CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY

REGIONAL WATER QUALITY CONTROL BOARD
CENTRAL VALLEY REGION

USE ATTAINABILITY ANALYSIS

FOR
AMENDMENTS
TO
THE WATER QUALITY CONTROL PLAN
FOR THE SACRAMENTO RIVER AND
SAN JOAQUIN RIVER BASINS
FOR
BENEFICIAL USES
AT
WEST SQUAW CREEK
SHASTA COUNTY

Final Report
July 2004

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Abbreviations

APS	Alkaline Producing System
ARD	Acid Rock Drainage
BAT	Best Available Technology
BMI	Benthic Macroinvertebrate
BMP	Best Management Practice
BPJ	Best Professional Judgment
BPT	Best Practical Control Technology
$CaCO_3$	Calcium Carbonate
Cd	Cadmium
CFR	Code of Federal Regulations
CSBP	California Stream Bioassessment Procedure
CTR	California Toxics Rule
Cu	Copper
$CuFeS_2$	Chalcopyrite
CWA	Clean Water Act
DFG	California Department of Fish and Game
DWR	California Department of Water Resources
EB	Early Bird Tributary Stream Segment
EPT	*Ephemeroptera* (mayfly), *Plecoptera* (stonefly) and *Trichoptera* (Caddisfly) insect orders
ESA	Endangered Species Act
Fe^{2+}	Ferrous Iron
Fe^{3+}	Ferric Iron
Fe_2O_3	Hematite
FeOOH	Goethite
FeS_2	Pyrite
FR	Federal Register
gpm	Gallons per Minute
GPS	Global Positioning System
HDPE	High-Density Polyethylene
lb/day	Pounds per Day
LC_{50}	Lethal Concentration (50 percent survival)
mg/l	Milligrams per Liter
mg/kg	Milligrams per Kilogram
MRRC	Mining Remedial Recovery Company, Inc.
MSL	Mean Sea Level
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollution Discharge Elimination System
NTR	National Toxics Rule
OAL	Office of Administrative Law
PA	PA Tributary Stream Segment
psi	Pounds per Square Inch
SO_4^{2-}	Sulfate
RWQCB	Regional Water Quality Control Board
SRB	Sulfate Reducing Bacteria
SWRCB	State Water Resources Control Board
TMDL	Total Maximum Daily Load
UAA	Use Attainability Analysis

Abbreviations (continued)

USFWS	United States Fish and Wildlife Service
ug/l	Micrograms per Liter
umhos/cm	Micromhos per Centimeter
USC	United States Code
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WDR	Waste Discharge Requirements
WEIL	Weil Tributary Stream Segment
WIN	Windy Creek Stream Segment
WSC	West Squaw Creek Stream Segment
Zn	Zinc
ZnS	Sphalerite

Glossary

Abandoned Mine – Previously mined area and associated waste units, processing plants and other facilities that have not been reclaimed.

Acid – Substance that has a pH of less than 7, which is neutral. Specifically, an acid has more free hydrogen ions (H^+) than hydroxyl ions (OH^-).

Anadromous Fish – Fish that spawn in freshwater and spend a portion of their lives in the ocean.

ARD – Acid rock drainage is drainage that occurs as a result of oxidation of sulfide materials (usually pyrite or iron sulfide) contained in rock that is exposed to air and water. The oxidation of sulfides produces sulfuric acid and sulfate salts. The acid dissolves and leaches out minerals in the rock.

Adit – A nearly horizontal passage accessible from the surface for the purpose of working in or dewatering a mine.

Aerobic Organism – Organism that can utilize oxygen as the final electron acceptor during metabolism.

Alkalinity – Capacity of solutes in an aqueous system to neutralize acid.

Anaerobic Organism – Organisms that do not use oxygen as the final electron acceptor during metabolism, organisms that grow in the absence of air.

Anoxic – Absence of oxygen, dissolved oxygen concentrations are near zero.

Basin Plan – Water Quality Control Plan, Central Valley Region, Sacramento and San Joaquin River Basins, Fourth Edition, 1998.

BAT – Best available technology is used to describe the best and most stringent technology, treatment techniques, or other means available for controlling the water quality of point source discharge.

BMI – Benthic macroinvertebrates are stream-inhabiting organisms that spend at least part of their lives living in or on the stream bottom.

BMP – Best management practice is the practice or combination of practices that are determined to be the most effective, practical means of preventing or reducing the amount of pollution generated by nonpoint (and point) sources to levels compatible with water quality goals.

Bulkhead Seal – Generally a concrete plug installed in an adit or tunnel to: 1) prevent access, and 2) re-establish the pre-mining hydrostatic pressure behind the seal.

Clean Water Act – The Federal Water Pollution Control Act, popularly known as the Clean Water Act (CWA), is a comprehensive statute aimed at restoring and maintaining the chemical, physical, and biological integrity of the nation's waters. Originally enacted in 1948, the CWA was expanded numerous times until it was reorganized and expanded in 1972. It continues to be amended almost every year. The CWA is codified in the United States Code (33 USC 1251-1387). Regulations implementing the CWA are included in the Code of Federal Regulations (CFR).

Concentration – Mass of contaminant per unit volume of water generally expressed as milligrams per liter (mg/l) or micrograms per liter (ug/l), where 1 mg equals 10^{-6} kilograms and 1 ug equals 10^{-9} kilograms.

Glossary (continued)

Disseminated Gossan – Leached, oxidized surface exposure of a weathered disseminated sulfide deposit.

Disseminated Sulfide Deposit – Low-grade metal sulfide ore disseminated throughout host rock.

Drift – Nearly horizontal underground passage excavated along a vein.

Gabion – Wire mesh box-shaped baskets that are available in variable sizes. These baskets are filled with non-acid forming rocks and placed to form the floor and walls of a channel**.**

Gangue – Mine waste, consisting of barren rock, as well as target minerals in concentrations too low for economic recovery, synonymous with waste rock.

Gossan – Leached, oxidized surface exposure of a weathered sulfide deposit.

Gossan Float – Fragments of gossan carried away from the exposed sulfide deposit.

Mass Loading – Mass of contaminant per unit time generally expressed as pound per day (lb/day), which is calculated by multiplying the measured concentration of the contaminant in ug/l, by the measured flow rate in gallons per minute (gpm), by a unit conversion factor of 0.00001198.

Massive Gossan – Leached, oxidized surface exposure of a weathered massive sulfide deposit.

Massive Sulfide – High grade metal sulfide ore generally occurring in lenses or large mass.

Nonpoint Source Pollution – Pollution from any source that is not considered a point source. Can be natural or human-caused.

Ore – Rocks or minerals that can be recovered at a profit. In its strictest sense, ore refers only to metals or metal-bearing minerals.

Oxidation – In common usage, oxidation is a reaction between a substance and oxygen. More precisely, oxidation is any reaction in which an atom loses an electron. The reaction does not have to involve oxygen.

Periphyton – Algae and associated microorganisms growing attached to any submerged surface.

Point Source Pollution – Any discernible, confined, and discrete conveyance. Including, but not limited to, pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, landfill leachate collection system, vessel or other floating craft from which pollutants are or many discharge.

Portal – Entrance to an adit or tunnel.

Reduction – Reduction is any reaction in which an atom gains an electron.

Stope – An underground excavation formed by the extraction of ore.

Glossary (continued)

Sulfate Reducing Bacteria – Anaerobic bacteria that obtain the oxygen needed for metabolism by reducing sulfate (SO_4^{2-}) to hydrogen sulfide (H_2S) or elemental sulfur.

Sulfide – A metallic mineral containing sulfur such as pyrite (FeS_2), chalcopyrite ($CuFeS_2$) or sphalerite (ZnS).

Tailings – Residual material remaining after ore is processed.

TMDL – Total maximum daily load is a calculation of the maximum amount of a pollutant that a water body can receive and still meet water quality standards.

Tributary – A smaller stream that flows into a larger stream.

Tunnel – A long passage in a mine that is open at both ends.

Vein – Mineral filling a fault or fracture.

Waste Rock – Mine waste, consisting of barren rock, as well as target minerals in concentrations too low for economic recovery.

Watershed – The land area that drains water to a particular stream, a land feature that can be identified by tracing a line along the highest elevations between two areas on a map, often a ridge.

SECTION 1
Introduction

1.0 INTRODUCTION

A Use Attainability Analysis (UAA), as described in the Federal Water Quality Standards (40 CFR 131.10(g) and 131.3(g)) is “an assessment of the factors affecting the attainment of aquatic life uses or other beneficial uses, which may include physical, chemical, biological, and economic factors.” When a state, designated by the U.S. Environmental Projection Agency (USEPA) to implement the Clean Water Act (CWA), wishes to remove a designated beneficial use, the state shall conduct a UAA to justify the proposed change.

The purpose of this UAA for West Squaw Creek, a tributary to Shasta Lake, is to:

1. Show that, prior to 1975, metals contamination from historic mining operations in the West Squaw Creek watershed between the Early Bird tributary and Shasta Lake exceeded numeric water quality objectives currently identified to be protective of a warm and cold-water fishery,

2. Show that current levels of metal contamination in West Squaw Creek between the Early Bird tributary and Shasta Lake, although significantly less than the pre-1975 levels, continue to exceed the numeric water quality objectives identified to be protective of a warm and cold-water fishery,

3. Identify metal sulfide deposits as the cause of the impairment,

4. Show that the occurrence of metal sulfide deposits and historic mining activities in the West Squaw Creek watershed prevent the attainment of the numeric water quality objectives identified to be protective of a warm and cold-water fishery,

5. Provide the information necessary to justify amending the designated beneficial uses identified in the Water Quality Control Plan (Basin Plan), Central Valley Region, Sacramento and San Joaquin River Basins, Fourth Edition (RWQCB, 1998).

A portion of West Squaw Creek and its tributaries are the focus of this UAA. West Squaw Creek drains to Shasta Lake and, hence, to the Sacramento River. The designated beneficial uses for Shasta Lake are listed in Table II-1 of the Basin Plan, and West Squaw Creek is listed as a water quality limited segment in an appendix to the Basin Plan. General site location is shown in Figure 1-1. A site vicinity map, including watershed boundary and area features, is included in Figure 1-2.

The designated beneficial uses of Shasta Lake and West Squaw Creek, by application of the ‘tributary rule’ as described on page II-2.00 of the Basin Plan, include municipal and domestic supply (MUN), agricultural irrigation (AGR), hydropower generation (POW), contact and non-contact recreation (REC1 and REC2), freshwater habitat (WARM and COLD), spawning (SPWN), and wildlife habitat (WILD).

Historic mines in the West Squaw Creek watershed are currently regulated in accordance with a National Pollutant Discharge Elimination System (NPDES) permit under the CWA. This permit sets allowable discharge levels for point source discharges and is enforced by the Regional Water Quality Control Board (RWQCB). In accordance with the permit, metal loading (copper, cadmium and zinc) from point sources must be reduced by 99 percent, and receiving water concentrations must meet the numeric objectives identified for the protection of a warm and cold water fishery.

Discharge from abandoned and historic mine sites, such as those in the West Squaw Creek drainage, are unique from most NPDES regulated discharges. The facilities are inactive and many remedial technologies are not economically or technically feasible due to the remoteness and steepness of the terrain in the vicinity of the mines. Nevertheless, since remedial activities were initiated in 1978, point source discharges of acid rock drainage (ARD) to West Squaw Creek have been reduced by 95 percent, from 560 pounds per day (lb/day) to 30 lb/day. Overall, point and nonpoint discharge has been reduced by 80 percent, from 720 lb/day to 150 lb/day. Even with these reductions, the discharges continue to be in violation of the water quality objectives identified in the Basin Plan to be protective of a warm and cold-water fishery. These objectives are also exceeded in portions of West Squaw Creek not directly impacted by past mining activities.

Prior to the initiation of remedial activities in the watershed, discharge from point sources accounted for approximately 80 percent of the metal loading in West Squaw Creek. Currently, discharge from these point sources account for less than 20 percent of the metal loading in the watershed. The remaining metal loading is attributed to nonpoint sources, including naturally occurring sources.

This UAA is being prepared to support a Basin Plan Amendment for adoption by the RWQCB to modify the designated beneficial use of warm and cold freshwater habitat (WARM and COLD) to exclude fish and other metal or pH sensitive aquatic species, and to remove the designated, but not existing, beneficial use of warm and cold water spawning (SPWN) in West Squaw Creek from the Early Bird tributary to Shasta Lake.

When this amendment is adopted, NPDES permits regulating the abandoned mines in the West Squaw Creek watershed will be revised to incorporate the amendment by removing the unattainable water quality objectives for the protection of fish and other metal and pH sensitive aquatic species. The mine owners will continue to be responsible for monitoring, maintaining the existing remedial facilities, and implementing nonpoint source Best Management Practices (BMPs) as they are identified by the RWQCB.

The remainder of this section provides the regulatory context for basin planning, defines the purpose and need for revisions to the Basin Plan, presents the scope of the proposed revisions, and defines the purpose and intended use of this document in the overall Basin Plan amendment process.

1.1 BACKGROUND

1.1.1 Water Quality Control Plan (Basin Plan)

A Basin Plan is the basis for water quality regulatory actions by the RWQCB within California. The preparation and adoption of a Basin Plan is required by California Water Code Section 13240 and supported by the CWA. Section 303 of the CWA requires states to adopt water quality standards which consist of the designated uses of the navigable waters involved and the water quality criteria (referred to as "objectives" in California) for such waters based upon designated uses.

A Basin Plan must contain (Water Code Section 13240-13244):

a. Beneficial uses to be protected,
b. Water quality objectives,
c. A program of implementation needed for achieving water quality objectives,
d. Surveillance and monitoring to evaluate the effectiveness of the program.

Basin Plans are adopted and amended by the RWQCB using a structured process involving peer review, public participation, state environmental review, and federal agency review and approval.

It is the intent of the State Water Resources Control Board (SWRCB) and RWQCBs to maintain the Basin Plans in an updated and readily available edition that reflects the current water quality control program. The Basin Plan was first adopted in 1975. In 1989, a second edition was published. The second edition incorporated all the amendments which had been adopted and approved since 1975, updated the Basin Plan to include new state policies and programs, restructured and edited the Basin Plan for clarity, and incorporated the results of triennial reviews conducted in 1984 and 1987. In 1994, a third edition was published incorporating all amendments adopted since 1989, including new state policies and programs, restructuring and editing the Basin Plan to make it consistent with other regional and state plans, and substantively amending the sections dealing with beneficial uses, objectives, and implementation programs. The current edition (Fourth Edition, 1998) incorporates two new amendments adopted since 1994. One amendment deals with compliance schedules in permits and the other addresses agricultural surface drainage discharges.

Since publication of the Fourth Edition, federal rules regarding USEPA approval of water quality standards have changed. When a state adopts a water quality standard that goes into effect under state law on or after May 30, 2000, it becomes the applicable water quality standard only after USEPA approval, unless the USEPA promulgates a more stringent water quality standard for that state, in which case the USEPA promulgated water quality standard is the applicable water quality standard for purposes of the CWA (65 FR 36046 codified at 40 CFR 131.21). This new regulation applies to all surface waters of the state.

1.1.2 Regulatory Authority

The SWRCB and the nine RWQCBs are the principal state agencies with regulatory responsibility for coordination and control of water quality. The Porter-Cologne Water Quality Control Act (California Water Code Section 13000 et seq.) establishes the requirement to adopt and revise state policy for water quality control. Basin Plans adopted by the RWQCBs must conform to these policies.

Authority for each RWQCB to formulate and adopt Basin Plans and periodically review the plans is provided in Section 13240 of the Water Code. A Basin Plan does not become effective, however, until approved by the SWRCB (Water Code Section 13245) and the Office of Administrative Law (OAL). If the amendment involves adopting or revising a standard that relates to surface water, it must also be approved by the USEPA before it goes into effect.

Section 303 of the CWA requires states to adopt water quality standards for surface waters "…*from time to time*…" and "…*as appropriate*…." Standards consist of designated uses and criteria (referred to as "objectives" in California) to protect those uses. These requirements also are found primarily in 40 CFR 130 (which covers water quality planning and management) and 40 CFR 131 (which covers water quality standards).

This UAA provides the information required by the RWQCB to justify an amendment to the Basin Plan for the Sacramento and San Joaquin River Basins.

1.1.3 Purpose and Need for the Proposed Revision to Beneficial Use Designation

In its most recent triennial review of the Basin Plan, as required by the CWA, the RWQCB identified the need to further develop solutions to water quality regulation problems associated with ARD and mine remediation (RWQCB, 1998). The focus of this document is to evaluate the existing water quality in West Squaw Creek, determine if current beneficial use designations are appropriate, determine whether stream specific changes to the currently applicable objectives for these parameters are appropriate, and, if so, propose and technically support such changes. This is consistent with the RWQCB's basin planning priority.

Since 1978, remedial efforts have concentrated on controlling point and nonpoint sources in an attempt to attain the prescribed water quality objectives for West Squaw Creek. These efforts have resulted in the removal of over 92 percent of the total copper loading, 68 percent of the zinc loading, and 81 percent of the cadmium loading reaching Shasta Lake. The impacted segment of West Squaw Creek, however, continues to exceed water quality objectives for pH, copper, zinc, and cadmium. Extensive discussions between RWQCB staff and the current owner of the abandoned West Squaw Creek mines (Mining Remedial Recovery Company or MRRC) resulted in consensus that pursuing modifications to the beneficial uses of West Squaw Creek offered an appropriate and reasonable means to:

1. Identify designated beneficial uses that accurately reflect the existing and potential uses of the water course,

2. Minimize the unnecessary expenditures of resources towards attaining water quality objectives that are not attainable using current technology, thus allowing available resources to be allocated on more serious water quality issues.

1.1.4 Background on West Squaw Creek

A portion of West Squaw Creek and its tributaries are the focus of this document. West Squaw Creek drains to Shasta Lake and, hence, to the Sacramento River. The water bodies in question are included in the Basin Plan. West Squaw Creek has been designated as an impaired water body under Section 303(d) of the CWA. The Basin Plan identifies the following beneficial uses for Shasta Lake: municipal and domestic supply (MUN); agricultural irrigation (AGR); hydropower generation (POW); contact and non-contact recreation (REC1 and REC2); freshwater habitat (WARM and COLD); spawning (SPWN); and wildlife habitat (WILD).

The Basin Plan, on page II-2.00, states: "Existing and potential beneficial uses which currently apply to surface waters of the basins are presented in Figure II-1 and Table II-1. The beneficial uses of any specifically identified water body generally apply to its tributary streams." The Basin Plan does not specifically identify beneficial uses for West Squaw Creek but does identify present and potential uses for Shasta Lake, to which West Squaw Creek is a tributary.

Between 1896 and 1919, Shasta County developed into one of the major copper mining and smelting regions of the United States. Numerous mines supported five copper smelters. Shasta County led California in total value of mineral production, excluding petroleum, during this period. Predominately, the mineral extracted was copper. Approximately 620,000,000 pounds of copper was produced. The copper industry created the economic stimulus that resulted in the development of Shasta County as a commercial center. The West Shasta Copper-Zinc District of Shasta County accounted for the major amount of copper production in California prior to 1946 (California Division of Mines and Geology, 1967). The copper resources of Shasta County are located along a horseshoe-shaped deposit (shown in Figure 1-3) approximately 30 miles in length and one-half mile to four miles wide that stretches from Whiskeytown Lake to the west to Highway 299 to the east. Historic geologic literature refers to this area as the "Copper Crescent." Mines in the area were developed extensively during the period from 1896 to 1919. Over a three-year period between 1919 and 1922, the smelters were shut down due to economics and pressure from farm interests related to fume damages to orchard crops (Kristofors, 1973). Due to the elimination of the smelters, the mines also ceased operation during this period. The mines have not operated appreciably since.

The majority of the mines within the West Shasta Copper-Zinc District had ceased operation by the early 1920s. Most of the mines were closed by a simple layoff of workers, salvaging what could be returned from the equipment, and abandoning the mine to nature. In some instances, the extensive underground workings of the mines were intentionally collapsed. The potential environmental impact of the exposure of the remaining sulfide ore bodies to oxygen and water was unknown. The portals, adits, and air vents introduce oxygen to the rocks, which, in the presence of water and sulfide minerals, results in the creation of sulfuric acid. The acidic water leaches residual metals from the ore, exiting the mines through existing seeps or portals.

The impact of ARD on the creeks of the West Shasta Copper-Zinc District was first documented in 1940 (Shaw, 1941). At that time, the seasonal flooding of the creeks and Sacramento River allowed for dilution of acidic waters. Following construction and filling of Shasta Dam, completed in 1945, ARD resulted in documented fish kills in the vicinity of the West Shasta Copper-Zinc District (DWR, 1969). Since 1939, attention has been directed at reducing ARD impacts on Shasta Lake and in the Sacramento River below Shasta Dam.

The RWQCB issued NPDES permits for the mines in the West Squaw Creek drainage in 1986. Since that time, the RWQCB has issued numerous Cease and Desist Orders for violations of receiving water and effluent limits. Due to inability to meet promulgated limits, mine owners were served with citizen suits under provisions of the CWA in June 1996.

In 1998, due to the failure of applicable technology to achieve water quality objectives, the RWQCB requested MRRC to perform a UAA, as provided in the Federal Water Quality Standards (40 CFR 131) and allowed by the CWA, to evaluate the appropriateness of current designated beneficial uses for West Squaw Creek.

1.2 OVERALL REGULATORY AUTHORITY

This section discusses the control of surface water discharges under the CWA. It includes a discussion of the jurisdictional elements under the CWA, effluent limitations adopted under the CWA, the State's implementation of this program, the further controls required to meet receiving water quality objectives, and the process to modify criteria.

1.2.1 Clean Water Act

The CWA regulates, among other matters, the discharge of pollutants from point sources into navigable waters of the United States. The discharge of metal-bearing acid mine drainage from mine sites into West Squaw Creek, and hence, into the Sacramento River, is the discharge of pollutants from a point source or sources into navigable waters of the United States. CWA controls are imposed on industries through NPDES permits, which are permitted on a case-by-case basis.

In establishing discharge limits, the permitting agency requires, at a minimum, that the discharger comply with the effluent limitations established under the CWA for the specific industrial category of the discharger. In the event there are no specific effluent limitations for the type of discharge at issue, the statute provides that the permit shall contain "such conditions as the Administrator determines are necessary to carry out the provisions of this chapter," CWA 402(a)(1)(B), 33 USC 1342(a)(1)(B). USEPA uses "best professional judgment" (BPJ) to establish the effluent limitations if there is no regulation for the specific discharge category.

The CWA's system of technology-based effluent controls establishes effluent limitations according to whether the discharge is from a new or existing source and whether the pollutant is conventional/toxic, or a non-conventional/non-toxic pollutant. Existing sources of toxic discharges, such as ARD, were initially required to achieve Best Practicable Control (currently available) Technology (BPT) and then later to achieve Best Available (economically achievable) Technology (BAT). New sources are subject to New Source Performance Standards.

1.2.1.1 Best Professional Judgment

In the absence of promulgated standards for effluent limitations, USEPA establishes effluent limitations using BPJ. Since there are no promulgated standards for discharges from historic abandoned mines, effluent limitations using BPJ can be established.

There are no developed technology-based effluent limitations for historic abandoned copper or pyrite mines. There are technology-based limitations for active coal, iron, copper, and zinc mines. The effluent limitations for these other mining activities have historically been applied to a host of abandoned mines, including those in the West Squaw Creek watershed. The RWQCB has used BPJ to establish an effluent limit of 99 percent reduction in metal loading.

1.2.1.2 Industry-Specific Effluent Limitations

Although there are no regulations that directly address effluent limitations from historic abandoned copper mines such as those associated with West Squaw Creek, there are a number of industry categories analogous to the West Squaw Creek discharges which have been used by the various regulatory agencies to set discharge controls in the past. Among these are effluent limitations that have been established for active coal mines, iron mines, and other metal mines.

40 CFR 434 includes effluent limitations for coal mining point sources, including special provisions in Subpart C on “Acid of Ferruginous Mine Drainage.” These sections also contain the effluent limitations for ore mining. It includes specific sections on iron ore (Subpart A), and metals including copper and zinc (Subpart J). 40 CFR 434.10 “applies to discharges from any coal mine at which the extraction of coal is taking place or is planned to be undertaken”; 40 CFR 440.10 “are applicable to discharges from (a) mines operated to obtain iron ore…; (b) mills beneficiating iron ores…”; and 40 CFR 440.100 “applicable to discharges from…mines that produce copper, zinc, …”

These regulations specifically apply to active, not historic abandoned, mining areas but have historically been applied in NPDES permits for various types of inactive mines. These standards were replaced with a narrative discharge standard in MRRC’s recent permits. BPT and BAT limits on discharges from existing point sources at active copper and zinc mines are established under 40 CFR 440.102(a) and 440.103(a).

1.2.1.3 BAT/BMP

As outlined in the CWA, existing sources of toxic discharges (point sources) were initially required to achieve BPT and then later achieve BAT. Nonpoint sources (such as waste rock piles) are remedied using BMPs.

BAT represents the maximum feasible pollution reduction for point sources, using the most stringent technology available for controlling discharge. BAT treatment requirements take into consideration that they are “economically achievable.” Major sources are required to use BAT, unless it can be demonstrated that it is not feasible due to ineffective uses of energy, or for environmental or economic reasons. In general, BAT for mine point source remedies include hydraulic controls to minimize discharge, portal plugging, and treatment (SWRCB, 1979).

The Nonpoint Source Program Strategy and Implementation Plan, originally adopted by the SWRCB in 1988 (SWRCB, 2000a), describes three general management approaches to be used to address nonpoint source problems. These are:

1. Voluntary implementation of best management practices,
2. Regulatory-based encouragement of best management practices,
3. Adopted effluent limits.

In general, the least stringent option that successfully protects or restores water quality is employed. Specific BMPs for mining nonpoint sources were identified in SWRCB (1979) Resolution 79-149, and typically consist of hydraulic controls such as surface water diversions, capping and sealing, regrading for infiltration control, and revegetation. These are included in Figure 1-4. More recently, BAT and BMPs are grouped together under BMPs.

1.2.2 California Basin Plans

The preparation and adoption of a Basin Plan is required by the California Water Code (Section 13240) and supported by the CWA.

Section 303 of the CWA, 33 USC 1313, provides for promulgation of water quality standards by the states. The standards consist of designated uses of water and water quality criteria based on the designated uses (40 CFR 131.3(i)). The criteria are "elements of State water quality standards, expressed as constituent concentrations, levels, or narrative statements, representing a quality of water that supports a particular use" 40 CFR 131.3(b). The RWQCB has adopted these water quality standards in the Basin Plans as water quality objectives.

According to Section 13050 of the California Water Code, Basin Plans consist of a designation or establishment for the waters within a specified area of beneficial uses to be protected, water quality objectives to protect those uses, and a program of implementation needed for achieving the objectives. State law also requires that Basin Plans conform to the policies set forth in the Water Code beginning with Section 13000 and any state policy for water quality control. Since beneficial uses, together with their corresponding water quality objectives, can be defined per federal regulations as water quality standards, the Basin Plans are regulatory references for meeting state and federal requirements for water quality control (40 CFR 131.20).

1.2.3 Beneficial Uses/Water Quality Objectives

Section 101(a)(2) of the CWA establishes an interim goal that, "wherever attainable . . . water quality which provides for the protection and propagation of fish, shellfish, and wildlife and provides recreation in and on the water be achieved." This goal is commonly restated as the waters should be "fishable and swimmable". States have the primary authority for defining and designating the uses to be protected in their waters. USEPA's water quality standards regulation (40 CFR 131) requires states to "take into consideration the use and value of water" for various uses, including protection and propagation of fish, shellfish, and wildlife, and recreation in and on the water, and prohibits the removal, sub-categorization, or failure to designate these CWA goal uses unless their attainment is infeasible due to one or more of six use attainability factors.

Uses may be designated as either existing or potential uses. An existing use is any use that has existed in the stream at any time since November 28, 1975 (40 CFR 131.3). Existing uses must be fully protected and cannot be removed (40 CFR 131.10(h)(1)). A potential use is a use that has not existed in the water body since November 28, 1975. A potential use may be removed or modified by the RWQCB by consideration of a formal UAA. To develop water quality standards, states first identify all attainable uses of a water body. States then adopt water quality standards for individual designated uses.

Water Quality objectives are set in the Basin Plans based on beneficial uses. The Porter-Cologne Water Quality Control Act defines water quality objectives as "… the limits or levels of water quality constituents or characteristics which are established for the reasonable protection of beneficial uses of water or the prevention of nuisance within a specific area" (Water Code Section 13050(h)). In establishing water quality objectives, the RWQCB considers, among other things, the following factors:

- Past, present, and probable future beneficial uses,

- Environmental characteristics of the hydrographic unit under consideration, including the quality of water available,

- Water quality conditions that could reasonably be achieved through the coordinated control of all factors which affect water quality in the area,

- Economic considerations,

- The need for developing housing within the region,

- The need to develop and use recycled water.

As noted earlier, California water quality standards include designation and protection of beneficial uses and the water quality objectives based on those uses.

States establish water quality criteria for a wide range of substances sufficient to protect the designated uses. Discharger effluent limits are based upon the water quality criteria. Criteria are usually expressed as maximum concentrations of individual substances that may be present in a water body without causing impairment of designated uses. The Basin Plan sets both numeric and qualitative standards. The numeric standards for the Sacramento River and its tributaries above State Highway 32 Bridge, that apply to the West Squaw Creek watershed, are summarized below:

- Cadmium – 0.22 ug/l,
- Copper – 5.6 ug/l,
- Zinc – 16.0 ug/l,
- pH – 6.5 - 8.5 (changes shall not exceed 0.5 units).

The numeric water quality standards for cadmium, copper, and zinc were established in 1985, and were intended to "fully protect the fishery from acute toxicity since the standards are based on short-term bioassays on the critical life stages of a sensitive species"; in this case anadromous salmonids. These numeric values vary logarithmically with hardness; however, the actual values stated are those listed in the Basin Plan and are based on a hardness of 40 mg/l.

The Basin Plan makes several relevant comments regarding water quality objectives. For example, they do not need to be met at the point of discharge, but at the edge of the mixing zone if areas of dilution are defined and should be attained and measured in the main water mass. Achievement of water quality objectives depend on applying them to "controllable water quality factors," which are defined as "those actions, conditions, or circumstances resulting from human activities that may influence the quality of the waters of the State, which are subject to the authority of the SWRCB or the RWQCB, and that may be reasonably controlled."

Under Section 303(d)(1) of the CWA, added by amendment in 1987, USEPA and the states were required to identify water bodies that are not achieving water quality standards due to toxic releases and to develop a control strategy for the sources. This program is in many respects a more focused effort akin to the water quality standards effort discussed above. West Squaw Creek, a tributary to Shasta Lake, is listed as a water quality limited segment pursuant to Section 303(d)(1) of the CWA.

1.2.4 California Toxics Rule

Federal regulations contained in 40 CFR 122.4(d) require effluent limitations for all pollutants that are, or may be, discharged at a level that will cause, or have the reasonable potential to cause, or contribute to an in-stream excursion above a narrative or numerical water quality standard. USEPA adopted the National Toxics Rule (NTR) on February 5, 1993, and the California Toxics Rule (CTR) on May 18, 2000. The NTR and CTR contain water quality standards applicable to this drainage. The SWRCB adopted the Policy for Implementation of Toxics Standards for Inland Surface Waters, Enclosed Bays, and Estuaries of California (SWRCB, 2000b), which contain guidance on implementation for the NTR and CTR.

1.2.5 Modifications of Water Quality Standards

Although the goal of the CWA is to ensure that all waters are "fishable and swimmable", the CWA and its regulations offer some flexibility to states to modify designated uses, water quality criteria, and the associated effluent limits to reflect local needs and conditions. The methods for modifying water quality standards and water quality-based permit limits in effluent-dependent streams are:

1. Alternate water quality criteria, such as site-specific criteria,
2. Use Attainability Analysis to modify beneficial uses.

A UAA may be used only if, (1) the existing uses in the stream will be protected and, (2) all controls required by Sections 301(b) and 306 of the CWA, as well as reasonable and effective best management practices for nonpoint sources have been implemented for the stream segment. The UAA process described in the federal regulations allows states to assess the feasibility of attaining the goal of "fishable and swimmable" uses in particular water bodies. The UAA can demonstrate that certain uses should be modified to reflect those that are actually attainable.

The UAA process provides six factors to assist in making this demonstration. Before conducting a UAA, states must demonstrate that the use under consideration is not an existing use. An existing use is one that has been attained in the water any time since November 28, 1975. 40 CFR 131.10(g) specifies the conditions under which a designated use may be removed from a stream:

> States may remove a designated use which is not an existing use, as defined in 40 CFR 131.3, or establish sub-categories of a use if the state can demonstrate that attaining the designated use is not feasible because:
>
> 1. Naturally occurring pollutant concentrations prevent the attainment of the use,
>
> 2. Natural, ephemeral, intermittent, or low-flow conditions prevent the attainment of the use, unless these conditions may be compensated for by discharge of sufficient volume of effluent discharges without violating state water conservation requirements to enable uses to be met,
>
> 3. Human caused conditions or sources of pollution prevent the attainment of the use and cannot be remedied or would cause more environmental damage to correct than to leave in place,
>
> 4. Dams, diversions, or other types of hydrological modifications preclude the attainment of the use, and it is not feasible to restore the water body to its original condition or to operate the modification in a way that would result in attainment of the use,

5. Physical conditions related to the natural features of the water body such as the lack of proper substrate, cover, flow, depth pools, riffles, and the like, unrelated to water quality, preclude attainment of aquatic life protection uses,

6. Controls more stringent than those required by Section 301(b) of the CWA would result in substantial and widespread economic and social impact.

The level of complexity and required documentation for UAAs will depend upon the situation. For example, when attempting to establish appropriate aquatic life uses, it may be relatively simple to demonstrate that certain aquatic life forms will be unable to exist in an area because of physical factors.

This UAA is based on criteria (3): "**Human caused conditions or sources of pollution prevent the attainment of the use and cannot be remedied or would cause more environmental damage to correct than to leave in place.**"

1.3 CONTENT AND ORGANIZATION

The document is organized as follows:

Section 1 – Introduction. Provides a historical and regulatory background for the Basin Plan amendment process, and defines the need for the proposed site-specific amendments.

Section 2 – Site History. Summarizes past remedial activities, and documents the levels of metal contamination prior to and following the completion of these activities.

Section 3 – Physical and Biological Assessment. Summarizes the physical conditions at site and the results of a biological assessment undertaken to determine current and potential future beneficial uses of West Squaw Creek. This section also includes a summary of a 1996 study undertaken to determine pre-mining or 'natural' water quality conditions.

Section 4 – Proposed Basin Plan Action. Identifies and designates existing beneficial uses for West Squaw Creek between the Early Bird tributary and Shasta Lake.

Section 5 – Alternatives Evaluation. Summarizes available remedial alternatives and the alternatives that have been implemented at the site.

Section 6 – References.

SECTION 2

Site History

2.0 SITE HISTORY

2.1 OPERATIONAL HISTORY

Major mining activity in the West Squaw Creek watershed was associated with the Balaklala group of mines. The Balaklala group of mines is located in the West Shasta Copper-Zinc District and was the second major mining complex developed along the Copper Crescent. Major mines included the Balaklala, Keystone, Shasta King, and Early Bird. The Balaklala Mine included the Windy Camp and Weil ore bodies (Kinkel, et al., 1956). MRRC acquired the Keystone Mine from Sharon Steel Corporation in 1991, and purchased the Balaklala, Shasta King, and Early Bird mines from Alta Gold Company in 1996. Key mining areas are shown on Figure 2-1.

Balaklala mining claims are reported to have included some of the largest ore bodies in the region, if not California (Kinkel et al., 1956). The Balaklala Mine operated from 1902 to 1928, with peak production between 1906 and 1919. Ore production from the Balaklala Mine was an order of magnitude greater than ore production from the other areas.

Mine	Ore Production (tons)
Balaklala (Windy Camp and Weil)	1,200,000
Keystone	121,800
Shasta King	83,900
Early Bird	40,100

The history of the Keystone Mine is not well documented. Claims at the mine were patented as early as 1908 and production ceased in 1925. Claims at the Shasta King Mine were patented before 1905 by the Trinity Copper Company. The mine operated from 1902 to 1909, and again from 1918 to 1919. Ownership and key milestones of mine activity are included in Table 2-1 (California Division of Mines and Geology, 1967).

In 1905, a smelter was constructed on the Sacramento River at Coram to process ore from the Balaklala group of mines. The town of Coram, or Coram Station, included a furnace house, blower building, matte and roaster buildings, dust chamber and smokestack, ore bins, machine and repair shops, assay office, laboratory office, and residences. The Coram smokestack was 18 feet in diameter and 250 feet high. By 1908, at the height of operations, the town of Coram had a population of more than 2,000. The Coram smelter operated until 1911 (Kristofors, 1973).

An aerial tramway over 16,200 feet long was used to transport ore from the mines to the Coram smelter. The tramway had a capacity of 75 tons per hour. Numerous wagon roads also connected the mines to the smelter and to numerous adjacent towns and smelters. Despite its great size and expected potential, the smelter ceased operation in 1911. The inability of the company to install adequate fume control devices resulted in numerous lawsuits and, eventually, the closure of the smelter. By 1919, all of the remaining local smelters including those at Keswick, Kennett, Bully Hill, and Ingot were closed by court order. The closure of the smelters was the beginning-of-the-end for copper mining in Shasta County (Kristofors, 1973).

Table 2-1 MINE ACTIVITY WEST SQUAW CREEK WATERSHED	
Date	**Owner/Activity**
Balaklala Mine	
pre-1900	Mine patented by W.M. Murray, owner of Stowell and Windy Camp.
1900	Mine developed by the Balaklala Mining Company of San Francisco.
1902-1905	Western Exploration Company secures a bond on the property. Extensive development of the property is undertaken.
1905	Assets acquired by the First National Copper Company and transferred to the White Knob Copper Company, Ltd., of MacKay, Idaho. Establishment of the Balaklala Consolidated Copper Company as the operating concern.
1906	Completion of the largest and most modern smelter on the Pacific Coast at site near Coram.
1910	Cottrell fume control device installed at smelter in response to farmer protests.
1911	A successful suit by the Shasta County Farmers' Protective Association closes the smelter. Intermittent operations until active operations resumed in 1914.
1919	Active operations cease.
1924-1925	Mammoth Copper Company (US Smelting, Refining & Mining Co.) reopens the mine under lease.
1926-1928	Mason Valley Mines mines ore from pillars under lease.
1948	Weil tunnel is reopened, unknown party.
1954	Claims leased to Shasta Minerals & Chemicals Co.
1955-1957	Shasta-Phelps Dodge Joint Venture conducts exploration.
1961	Shasta Minerals & Chemicals Co. purchases property.
1970's	Silver King Mines obtains ownership of the mine.
1989	Silver King Mines changes name to Alta Gold.
1996	MRRC obtains ownership of the mine from Alta Gold.
Shasta King Mine	
1902-1909	Main holding of the Trinity Copper Company.
1909-1917	Operations idle.
1918-1919	Operations resumed under lease to US Smelting, Refining & Mining Co.
1923	Assets transferred to Federal National Bank of Boston.
1923-1954	Leased to Walker Engineering Corp.
1954	Leased to Shasta Copper & Uranium Co.
1955-1957	Shasta-Phelps Dodge Joint Venture conducts exploration.
1961	Sold to Shasta Minerals & Chemical Co.
1970's	Silver King Mines obtain ownership of the mine.
1989	Silver King Mines change name to Alta Gold.
1996	MRRC obtains ownership of the mine from Alta Gold.
Keystone Mine	
1908	Stevenson, Grotefend and Slemner of Redding patent claim and own mine.
1917	Sold to Exploration Company
1921	Sold to by US Smelting, Refining & Mining Co.
1972	US Smelting, Refining & Mining Co. changes name to UV Industries.
1979	Sharon Steel buys UV Industries.
1991	MRRC obtains ownership of the mine.
Early Bird Mine	
1918	Main ore body discovered.
1922	Leased to US Smelting, Refining & Mining Co.
1922-1928	Leased to Mason Valley Mines.
by 1956	Owned by Balaklala Consolidated Copper Company.
Sources: Kinkel, et al. (1956), California Division of Mines and Geology (1967), MRRC (2003a)	

2.2 PROBLEM IDENTIFICATION

Many of the first recorded studies of ARD as an environmental concern were carried out during the construction of Shasta Dam. Shaw (1941) reported copper concentrations, pH, and flow for five streams found to be contaminated by ARD. Copper and pH values were determined colorimetrically on unfiltered, unpreserved samples. The five streams were sampled monthly between March 1940 and March 1941. Average copper loading to the Sacramento River during the study was estimated to be in excess of 500 lb/day. Using Shaw's data, contributions to the total copper load are estimated to be 2 percent from Town Creek, 3 percent from Horse Creek, 15 percent from Little Backbone Creek, 26 percent from West Squaw Creek, and 54 percent from Spring Creek. Conclusions reached by Shaw were: (1) concentrations of copper are highest during low-flow conditions, (2) all five streams are toxic to fish, (3) the highest levels of contamination occur near Kennett at the junction of West Squaw Creek and Little Backbone Creek, and (4) although copper concentrations tend to decrease during high flows, the copper load increases.

California Department of Water Resources (DWR) produced a report on the water quality of West Squaw Creek (DWR, 1969). A systematic sampling program was established in 1968 and completed in spring of 1969. A gauging station was installed at the mouth of West Squaw Creek and a rating curve established. The drainage was planimetered and the tributaries identified. The study verified that discharges from mine workings resulted in increased copper concentrations. The study also addressed the seasonality of fish kills and suggested remedial measures. These measures included rerouting of stream channels, surface water diversions, sealing mine portals, and improving waste rock areas.

Fish kills were documented by Hansen and Weidlein (1974). Their investigation evaluated West Squaw Creek from September 1968 to July 1969. The pH, copper, and stream discharge were measured three times a month except during May and July. As fish kills occurred, the species were identified, the count reported, and the mass of fish measured. Copper concentrations on the surface and near the bottom of the West Squaw arm of Shasta Lake were also measured at various distances up to 1,645 meters from the mouth of West Squaw Creek. The difference in surface-to-bottom concentrations of copper suggested stratification regardless of the time of year; although winter copper concentrations are usually higher than those in summer, regardless of depth. Two major conclusions reached by Hansen and Weidlein were: (1) fish kills are related to the time and location of fish planting in addition to periods of high copper discharges, and (2) toxic copper concentrations extend a minimum of 1,645 meters into Shasta Lake from the mouth of West Squaw Creek.

U.S. Geological Survey (1978) conducted an evaluation of problems arising from ARD near Shasta Lake. The document was prepared in conjunction with the RWQCB. The document relied heavily on the work of others and presented a number of alternatives for remediation. This report was among the first reports to suggest that waste rock piles may contribute significantly to metals concentrations.

DWR (1983) conducted a detailed evaluation of ARD in the West Squaw Creek drainage. The report presented monitoring results from 14 sites, including portals and waste rock piles at the Balaklala, Keystone, and Shasta King mines in the West Squaw Creek drainage. Monitoring was conducted from November 1982 through April 1983. Mass balances were calculated for copper and zinc. The copper balance showed that the Balaklala portal accounted for the majority of the copper in West Squaw Creek. In addition, the study identified seasonal variation in discharge and speculated that the creeks store a portion of the metal loading which is discharged later in the year.

The RWQCB retained CH2M HILL (1985) to study methods to control or eliminate the ARD being discharged to Little Backbone Creek and Shoemaker Gulch from the Mammoth, Golinsky, and Sutro mines. The Little Backbone drainage is located northeast of the West Squaw Creek drainage and includes several mines owned by MRRC. The study was funded by a USEPA grant under Section 205 (j) of the CWA, and by funds allocated from the SWRCB. The purpose of the study was to evaluate existing and proposed measures for mitigating fish kills and other adverse impacts caused by ARD from inactive mines in the study area. A primary emphasis of the study was to evaluate the effectiveness of bulkhead seals installed during the early 1980s, including the plugging program carried out by Sharon Steel Corporation, a predecessor to MRRC. The results of this evaluation were used to assess the feasibility of installing additional bulkhead seals to reduce metal loading in receiving waters. Other potential control measures were reviewed on a reconnaissance level. Alternatives were assessed in terms of their relative feasibility and cost-effectiveness in controlling ARD.

Significant background reports and agency permits generated over the last 60 years are listed below.

2.2.1 Background Reports

- Shaw, P. 1941. Mine Tunnel Drainage in the Shasta Reservoir Area. California Division of Fish and Game.

- Kinkel, A.R., W.E. Hall and J.P Albers. 1956. Geology and Base-Metal Deposits of West Shasta Copper-Zinc District, Shasta County, California. United States Geological Survey Professional Paper 285.

- DWR. 1969. *Squaw Creek Copper Investigation: Memorandum Report.* California Department of Water Resources.

- Weidlein, W. 1971. *Summary Progress Report on the Shasta Lake Trout Management Investigations, 1967 through 1970.* California Department of Fish and Game.

- Hansen, R.J. and W.D. Weidlein. 1974. *Investigation of Mine Drainage Related to Fish Kills in the Little Squaw Creek Arm of Shasta Lake, Shasta County, California.* California Department of Fish and Game, Administrative Report 74-2.

- USGS. 1976a. *Heavy Metal Discharges into Shasta Lake and Keswick Reservoirs on the Upper Sacramanto River, California, A Reconnaissance During Low Flows.* United States Geological Survey, Water Resources Investigation 76-49.

- USGS. 1976b. *The Weathering of Sulfide Ores in Shasta County, California, and its Relationship to Pollution Associated with Acid Mine Drainage.* United States Geological Survey, Open File Report 76-395.

- USGS. 1978. *An Evaluation of Problems Arising from Acid Mine Drainage in the Vicinity of Shasta Lake, Shasta County, California.* United States Geologic Survey, Water Resources Investigation 78-32.

- RWQCB. 1979. *Inventory and Assessment of Water Quality Problems Related to Abandoned and Inactive Mines in the Central Valley Region of California.*

- DWR. 1983. *Quantification of Acid Mine Discharges from Mine Portals and Dumps at Balaklala, Keystone and Shasta King Mines.* California Department of Water Resources.

- CH2M HILL. 1985. *Mammoth Mine Water Quality Management Planning Study,* prepared for California Water Quality Control Board, Central Valley Region.

2.2.2 Agency Permits

- California Regional Water Quality Control Board, Central Valley Region, Order No. 78-153. *Waste Discharge Requirements for Silver King Mines, Inc., Balaklala, Keystone, and Shasta King Mines, Shasta County.*

- California Regional Water Quality Control Board, Central Valley Region, Order No. 85-136. *Waste Discharge Requirements for Silver King Mines, Inc., Balaklala, Keystone, and Shasta King Mines, Shasta County.*

- California Regional Water Quality Control Board, Central Valley Region, Order No. 86-142 (NPDES CA0081868). *Waste Discharge Requirements for Silver King Mines, Inc., Balaklala, Shasta King and Early Bird Mines, Shasta County.*

- California Regional Water Quality Control Board, Central Valley Region, Order No. 86-143. *Requiring Shasta King Mines, Inc., to Cease and Desist from discharging waste contrary to Waste Discharge Requirments, Balaklala, Shasta King, and Early Bird Mines, Shasta County.*

- California Regional Water Quality Control Board, Central Valley Region, Order No. 86-144 (NPDES CA0081876). *Waste Discharge Requirements for Sharon Steel Corporation, Mammoth, Keystone, and Stowell Mines, Shasta County.*

- California Regional Water Quality Control Board, Central Valley Region, Order No. 86-145. *Requiring Sharon Steel Corporation to Cease and Desist from discharging waste contrary to Waste Discharge Requirements.*

- California Regional Water Quality Control Board, Central Valley Region, Order No. 87-081.

- California Regional Water Quality Control Board, Central Valley Region, Order No. 91-120 (NPDES CA0081876). *Waste Discharge Requirements for Mining Remedial Recovery Company, Inc. Mammoth, Keystone, and Stowell Mines, Shasta County.*

- California Regional Water Quality Control Board, Central Valley Region, Order No. 91-121. *Requiring Mining Remedial Recovery Company, Inc., Mammoth, Keystone, and Stowell Mines, Shasta County to Cease and Desist from Violating Waste Discharge Requirements.*

- California Regional Water Quality Control Board, Central Valley Region, Order No. 92-090, (NPDES CA0081868). *Waste Discharge Requirements for Alta Gold Company, Balaklala, Shasta King, and Early Bird Mines, Shasta County.*

- California Regional Water Quality Control Board, Central Valley Region, Order No. 95-254. *Requiring Alta Gold Company, Balaklala, Shasta King, and Early Bird Mines, Shasta County to Cease and Desist from Violating Waste Discharge Requirements.*

- California Regional Water Quality Control Board, Central Valley Region, Order No. 96-154, (NPDES CA0081876). *Waste Discharge Requirements for Mining Remedial Recovery Company, Inc., Mammoth, Keystone, Stowell, Balaklala, Shasta King, and Early Bird Mines, Shasta County.*

- California Regional Water Quality Control Board, Central Valley Region, Order No. 96-155. *Requiring Mining Remedial Recovery Company, Inc., Mammoth, Keystone, Stowell, Balaklala, Shasta King and Early Bird Mines, Shasta County to Cease and Desist from Violating Waste Discharge Requirements.*

- California Regional Water Quality Control Board, Central Valley Region, Special Order No. 98-220. *Special Order for Mining Remedial Recovery Company, Inc., Mammoth, Keystone, Stowell, Balaklala, Shasta King, and Early Bird Mines, Shasta County, Amendment of Cease and Desist Order No. 96-155.*

- California Regional Water Quality Control Board, Central Valley Region, Order No. R5-2002-153, (NPDES CA0081876). *Waste Discharge Requirements for Mining Remedial Recovery Company, Inc., Mammoth, Sutro, Keystone, Stowell, Balaklala, Shasta King, and Early Bird Mines, Shasta County.*

- California Regional Water Quality Control Board, Central Valley Region, Order No. R5-2002-154. *Cease and Desist Order for Mining Remedial Recovery Company, Inc., Mammoth, Sutro, Keystone, Stowell, Balaklala, Shasta King, and Early Bird Mines, Shasta County.*

2.3 SOURCE AREAS

The RWQCB issued the first Waste Discharge Requirements (WDRs) to address ARD contaminated water in the West Squaw Creek watershed in 1978. Since this time, the mine owners have completed an extensive program to reduce ARD entering West Squaw Creek. This program has focused on point and nonpoint sources associated with the Weil, Early Bird, Shasta King, Windy Camp, and Keystone areas. The first NPDES permit to control discharge from these areas was issued in 1986.

2.3.1 Point Sources

A point source, as defined in the CWA (33 USC 1362 (14)), is "any discernible, confined, and discrete conveyance." This includes, but is not limited to, any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, landfill leachate collection system, vessel, or other floating craft from which pollutants are or may be discharged.

In the case of the West Squaw Creek drainage, portals, portal diversions, and tributaries from mined areas have been identified by the RWQCB as point sources and are to be remediated using BAT. BAT represents the maximum feasible pollution reduction for point sources, using the most stringent technology available for controlling water quality from point source discharges. BAT treatment takes into consideration "economically achievable" methodology. Major point source discharges are required to use BAT, unless it can be demonstrated that such BAT is not feasible due to the unavailability of energy sources, environmental concerns, or economic reasons. In general, BAT for mine point sources include hydraulic controls to minimize discharge, portal plugging, and treatment (SWRCB, 1979).

Potential point sources of ARD in the West Squaw Creek watershed are shown in Figure 2-2. Prior to the onset of active remediation in 1980, more than 90 percent of the copper loading observed in West Squaw Creek at Shasta Lake originated from the following portals (MRRC, 2003b):

Portal	Copper Contribution (Percent)
Main Weil	75
Lower Windy Camp (Balaklala 11)	10
Main Keystone	3
Lower Shasta King	2
Early Bird	1.5
Upper Windy Camp (Tunnel 8)	1
	92.5

2.3.2 Nonpoint Sources

The CWA defines nonpoint source pollution as originating from sources that are not classified as point sources. In general, nonpoint source pollution is caused by rainfall or snowmelt moving over and through the ground. As the runoff moves, it can pick up and carry away natural and human-made pollutants, depositing them into lakes, rivers, wetland, coastal waters, and even underground sources of drinking water (SWRCB, 2000a). BMPs have been identified as the best technology available for controlling nonpoint source pollution. In general, BMPs are physical activities that reduce, rather than eliminate, nonpoint source discharges. Typical BMPs identified for ARD from abandoned mines include hydraulic controls such as surface water diversions, capping and sealing, regrading for infiltration control, and revegetation (SWRCB, 1979).

In accordance with the Nonpoint Source Program Strategy and Implementation Plan (SWRCB, 2000a), some nonpoint sources have been reevaluated and identified as point sources. For example, tailings generated from the ore processed at a smelter are identified as a potential source that may be reevaluated from the nonpoint to point source category. In contrast, waste rock associated with mine tunnels is defined as barren rock consisting of no desirable or acid-producing minerals, or minerals in concentrations too low for economic recovery. Water discharging from waste rock piles is still considered a nonpoint source.

Potential nonpoint sources of ARD identified within the West Squaw Creek drainage, including waste rock piles, natural disseminated gossan areas, and massive gossan areas, are shown on Figure 2-3. Prior to the onset of remediation in 1980, less than 10 percent of the copper loading observed in West Squaw Creek at Shasta Lake originated from nonpoint sources (MRRC, 2003b).

2.4 REMEDIAL ACTIVITY SUMMARY

Major remedial activities completed in the Weil, Early Bird, Shasta King, Windy Camp, and Keystone areas between 1980 and October 2003 are summarized in this section. To illustrate the scope of these activities, representative photographs are included in this section. Additional details and documents are on file with the RWQCB office in Redding, California.

2.4.1 Weil Area

1980 – Weil Bulkhead Seal (Figure 2-4). The initial bulkhead seal was installed in the Weil Tunnel in November 1980. This seal was reinforced with an additional 18 inches of concrete in December 1981 and another 20 inches of concrete in 1987. Prior to the installation of this seal, portal discharge averaged approximately 60 gallons per minute (gpm), and copper and zinc loading was in excess of several hundred pounds per day (MRRC, 2003b). Currently, the seal has eliminated discharge from the portal and the hydraulic pressure behind the seal varies between 92 and 107 pounds per square inch (MRRC, 2003b). The maximum pressure is controlled by the elevation of the 170-Level portal, approximately 230 feet above the main Weil portal (Kinkel, et al., 1956). The 170-Level provided access to the upper-most (170-foot) level of the Weil ore body. The hydraulic pressure behind the Weil bulkhead seal indicates that the seal successfully flooded the historic mine workings.

2003 – Weirs and Continuous Recording Stations (Figure 2-5). Two weirs and continuous recording stations were installed on the Weil tributary, up and downstream from the Weil waste rock pile in 2003. These recording stations were installed to: (1) evaluate seasonal discharge from the 170-Level portal, and (2) verify that the main Weil waste rock pile is not a significant source of ARD.

2.4.2 Early Bird Area

1987 – Early Bird Bulkhead Seal (Figure 2-6). A bulkhead seal was installed in the Early Bird adit in 1987.

1989 – Early Bird Bulkhead Seal Grout Curtain. Boreholes were drilled into rock surrounding the bulkhead seal, and the rock was pressure grouted to reduce leakage in June and August 1989. The bulkhead seal and grout curtain reduced metal loading entering the Early Bird tributary by 100 percent. Prior to sealing, approximately five lb/day copper and three lb/day zinc discharged from the Early Bird portal (MRRC, 2003b).

2.4.3 Shasta King Area

1989 – Shasta King Bulkhead Seal (Figure 2-7). A bulkhead seal was installed in the Lower Shasta King portal (Adit 11) in July 1989. The rock surrounding the seal is fractured and the seal developed a leak in late 1991. Between 2000 and 2003, discharge from the portal contributed approximately three lb/day copper and three lb/day zinc to West Squaw Creek. Very little pre-plug analytical data are available for the Lower Shasta King Portal (MRRC, 2003b).

1991 – Shasta King Bulkhead Seal Repair. The original bulkhead seal was repaired in August 1991, and again in November 1994.

2003 – Shasta King Bulkhead Seal Replacement (Figure 2-8). A new bulkhead seal and grout curtain were installed in front of the original bulkhead seal in October 2003. The objective of the new seal and grout curtain was to reduce leakage around the original bulkhead seal installed in 1989.

2.4.4 Windy Camp Area

1985 – Lower Windy Camp (Balaklala 11) Bulkhead Seal (Figure 2-9). A bulkhead seal was installed in the Lower Windy Camp portal in September 1985.

1985 – Upper Windy Camp Bulkhead Seal. A bulkhead seal was installed into an Upper Windy Camp portal in September 1985. Shepard Miller (1996a) reported that this seal was installed in a portal located at an elevation of 2480. This elevation corresponds with Tunnel 8.

1987 – Upper Windy Camp Glory Hole. The Upper Windy Camp glory hole was backfilled with waste rock from the nearby waste rock pile. The glory hole was the remnants of a collapsed stope associated with the Windy Camp ore body. Prior to being backfilled, flow in Upper Windy Creek disappeared into the glory hole, which was hydraulically connected to the Lower Windy Camp (Balaklala 11) portal.

1988 – Lower Windy Camp (Balaklala 11) Bulkhead Seal Replacement. The Lower Windy Camp bulkhead seal was replaced in October 1988. The original seal leaked and eventually failed along its toe.

1989- Lower Windy Camp (Balaklala 11) Bulkhead Seal Grout Curtain. Boreholes were drilled into rock surrounding the replacement seal and the rock was pressure grouted to reduce leakage in June and July 1989. The replacement seal and grout curtain reduced copper loading by 99 percent and zinc loading by 98 percent. Prior to sealing, approximately 30 lb/day copper and 41 lb/day zinc discharged from the Lower Windy Camp portal. Since 2000, metal discharge has been less than 0.5 lb/day for both copper and zinc (MRRC, 2003b).

1996 – Upper Windy Camp Gabion Channel (Figure 2-10). A high-density polyethylene (HDPE) lined gabion channel was constructed across the backfilled glory hole and the Upper Windy Camp waste rock pile in 1996. The objective of the channel was to eliminate water loss from Windy Creek to the glory hole and underlying waste rock.

1996 – Lower Windy Camp Waste Rock Pile. Approximately 40,000 cubic yards of waste rock from the Lower Windy Camp waste rock pile was excavated and relocated to the Upper Windy Camp waste rock pile. This waste rock was originally located in the Windy Creek stream channel.

1996 – Upper Windy Camp Anoxic Limestone Drain. An anoxic limestone drain was installed to collect and treat seepage from the Upper Windy Camp portal. This portal was uncovered during the waste rock relocation project and analytical data prior to the installation of the anoxic limestone drain are not available. The seepage may be from the bulkhead seal installed in 1984. Discharge from the anoxic limestone drain enters Windy Creek. Between 2000 and 2003, discharge from the drain contributed approximately three lb/day copper and six lb/day zinc to Windy Creek, a tributary to West Squaw Creek (MRRC, 2003b). The current levels are probably similar to pre-drain levels.

1996 – Upper Windy Camp Waste Rock Pile (Figure 2-11). The Upper Windy Camp waste rock pile, along with the waste rock relocated from the Lower Windy Camp, was graded and planted to reduce infiltration.

1996 – Lower Windy Camp (Balaklala 11) Rehabilitation. The Lower Windy Camp portal was rehabilitated after a landslide in 1990 damaged a portion of the tunnel located between the tunnel entrance and the bulkhead seal constructed in 1985.

2003 – Weir and Continuous Recording Station. A weir and continuous recording station was installed on lower Windy Creek. This recording station was installed to monitor the overall success of the remedial activities completed in the Balaklala and Keystone areas.

2.4.5 Keystone Area

1992 – Keystone Mine Bulkhead Seals (Figure 2-12). Bulkhead seals were installed in the main Keystone portal (400-Level) and in two secondary portals (275-Level and East Adit) in 1992. Discharge from the main portal was approximately 80 gpm prior to the installation of the bulkhead seal (MRRC, 2003b). A blowout occurred uphill from the main portal immediately following the installation of the seal.

1996 – Upper Windy Creek Diversion (Figure 2-13). A diversion structure and 1,600-foot HDPE-lined channel was constructed to divert Upper Windy Creek around the Upper and Lower Windy Camp waste rock piles. The diverted water is routed back into Windy Creek downstream from the waste rock piles.

1998 – Keystone Waste Rock Pile. The Keystone waste rock pile was graded, capped and planted in 1998, prior to the construction of the Keystone wetland unit.

1998 – Keystone Tunnel Limestone Injection (Figure 2-14). Eleven boreholes were drilled into 600 feet of the 400-Level tunnel, immediately behind the main Keystone portal, to inject approximately 200 tons of limestone. Additional boreholes were drilled and limestone was injected into mine workings further in the mountain. The objective of the limestone injection project was to improve the quality of water discharging from the blowout and main bulkhead seal by increasing pH. Based on video logging conducted during the injection operations, a location was selected for the placement of a remote bulkhead seal. This location was approximately 400 feet in from the externally placed bulkhead seal.

1999 – Remote Keystone Bulkhead Seal. A remote bulkhead seal was placed in the 400-Level tunnel by injecting limestone to create two cofferdams and injecting concrete between the cofferdams. The objective of the remote seal was to reduce discharge from the blowout and main Keystone portal. A temporary reduction in discharge was recorded following placement of the seal.

2000 – Keystone Wetland Unit (Figure 2-15). A quarter-acre wetland treatment unit was constructed to treat discharge from the main Keystone portal. The unit was designed to treat 50 gpm. Currently, approximately 25 gpm from the main Keystone portal is routed through the unit. Flow from the blowout is approximately 20 gpm (MRRC, 2003b).

2000 – Keystone Clear Water Diversion Channel (Figure 2-16). A concrete channel was constructed to divert clean water from a small tributary located near the main Keystone portal into the upper reach of Upper Windy Creek. Prior to the construction of the channel, water from the tributary infiltrated into the Keystone waste rock pile.

2001 – Remote Keystone Bulkhead Seal Rehabilitation. In an attempt to improve the remote Keystone seal, 24 boreholes were drilled in the vicinity of the previously placed remote seal. The tunnel was dewatered and additional concrete was injected. Currently (MRRC, 2003b), average annual discharge from the blowout (20 gpm) and main bulkhead seal (25 gpm) are approximately 50 percent of the pre-plug levels (80 gpm).

2003 – Upper Windy Creek Diversion Maintenance. Sediment was removed from the 1,600-foot HDPE-lined channel installed in 1996 to divert Upper Windy Creek around the Upper and Lower Windy Camp waste rock piles. Following sediment removal, holes and tears in the HDPE were repaired.

2.4.6 Other Areas

In addition to the remedial activities described above, MRRC has plans to address the Keystone blowout, seepage from the Upper Windy Camp portal, and seasonal discharge from the 170-Level portal. Proposed activities include:

2004 - Keystone Blowout. MRRC will modify operations of the Keystone wetland to receive discharge from the blowout. Currently, flow through the wetland averages 25 gpm (MRRC, 2003b). The system was designed to treat up to 50 gpm and, as mentioned, the average flow rate from the blowout is 20 gpm. MRRC has been operating a test cell using discharge from the Keystone blowout to evaluate methods, such as adding ethanol and nutrients, to enhance the activity of sulfate reducing bacteria (SRB) in the wetland. The results of this evaluation suggest that the wetland may be able to treat more than 50 gpm.

2004 - Upper Windy Camp Portal (Figure 2-17). MRRC plans to install a treatment unit to address seepage from the Upper Windy Camp portal. The average flow rate from the anoxic limestone drain is approximately 30 gpm (MRRC, 2003b).

2004 – 170 Level Portal (Figure 2-18). MRRC will address discharge from the 170 Level portal if data from the continuous recorders installed on the Weil tributary indicate that seasonal flow from this portal is a significant source of ARD.

2.4.7 Summary

Remedial activities conducted between 1980 and 2003 have reduced copper loading in West Squaw Creek, as measured at the West Squaw Creek Bridge, from an average annual rate of more than 300 lb/day to less than 25 lb/day (MRRC, 2003b). This represents an overall reduction of approximately 92 percent. The corresponding zinc and cadmium reductions are 68 percent and 81 percent. Additional details are provided below.

2.5 WATER QUALITY EVALUATION

The following analysis was conducted to estimate metal loading to West Squaw Creek prior to and after the completion of remedial activities described in the previous section. The analysis was conducted using data collected between 1939 and 2003.

Surface water data collected within the West Squaw Creek watershed are maintained in an ACCESS database (MRRC, 2003b). Through August 2003, the database included more than 10,000 records from more than 70 sample locations. The majority of the records represent pH, copper, zinc, cadmium, and flow data collected from 11 sample locations identified in discharge permits issued by the RWQCB. The permit locations are listed in Table 2-2 and shown on Figure 2-19. In general, the permit locations include portal discharge and receiving waters, such as West Squaw Creek. Data collected for regulatory compliance are obtained in accordance with sampling and analysis plans approved by the RWQCB. The annual distribution of database records is summarized in Figures 2-20 through 2-23.

The annual sum of pH, copper, zinc, cadmium, and flow records for surface water samples collected within the West Squaw Creek watershed is summarized in Figure 2-20. In general, the annual distribution of records reflects the occurrence of one time studies or RWQCB permit requirements. The studies and permits include:

Sampling Date	Study
1940 to 1941	DFG study by Shaw (1941)
1968 to 1969	DWR (1969) and Hansen and Weidlein (1974)
1982 to 1983	DWR (1983)
1986 to 1990	1986 NPDES Permit
1991 to 1995	1991 NPDES Permit
1996 to 2002	1996 NPDES Permit

Overall, 75 percent of the database records represent results from the 11 locations sampled for regulatory compliance. The annual sum of pH, copper, zinc, cadmium, and flow records for these locations is shown in Figure 2-21.

The annual sum of pH, copper, cadmium, zinc, and flow records for the West Squaw Creek Bridge, one of the locations sampled for regulatory compliance, is shown in Figure 2-22. The West Squaw Creek Bridge is located at the confluence of West Squaw Creek and Shasta Lake. Overall, more than 10 percent of the database records represent results from this location.

A more detailed breakdown of the records for the West Squaw Creek Bridge is shown in Figure 2-23. Between January and August 2003, 10 surface water samples from this location were analyzed for copper (nine dissolved samples and one total sample), pH was recorded seven times, and flow was recorded three times.

Table 2-2 REGULATORY SAMPLE LOCATIONS WEST SQUAW CREEK WATERSHED			
Permit ID[1]	**Database ID**	**Location**	**Permit**
004	Key 3.4	Main Keystone Portal	NPDES
010	Windy 5.1	Lower Windy Camp (Balaklala 11) Portal	NPDES
011	Squaw 8.1	Lower Shasta King Portal	NPDES
012	Early 1.1	Early Bird Portal	NPDES
013	Weil 2.1	Main Weil Portal	NPDES
015	Windy 2	Left Branch Windy Creek	RWQCB Request
016	Windy 2.1	Right Branch Windy Creek	RWQCB Request
017	Windy 9	Windy Creek Downstream	RWQCB Request
018	Windy 5	Upper Windy Camp Portal	RWQCB Request
R-5	Squaw 1	West Squaw Creek Upstream	NPDES
R-6	Squaw 15	West Squaw Creek at Bridge	NPDES

Notes:
[1] Permit ID sample designations are not sequential because the West Squaw Creek watershed is included in a NPDES permit that includes other MRRC properties located outside the watershed.

2.5.1 Mass Loading Summary

Bulkhead seals have been installed in three Keystone portals, Upper Windy Camp portal, Lower Windy Camp (Balaklala 11) portal, Lower Shasta King portal, Early Bird portal, and Weil portal. In accordance with the current NPDES permit, the success of a bulkhead seal is determined by comparing pre-plug metal loading with post-plug metal loading. Pre- and post-plug metal loading results for the bulkhead seals installed in the West Squaw Creek watershed are summarized in Tables 2-3 through 2-5. Assumptions used to develop these tables along with the appropriate database records are included in the Water Quality Appendix. For this analysis, mass loading was estimated using paired concentration and flow data.

As measured at the portals, copper loading has decreased 97 percent, zinc loading has decreased 93 percent, and cadmium loading has decreased 95 percent. The corresponding reductions observed in the receiving waters at the West Squaw Creek Bridge are 92 percent for copper, 68 percent for zinc, and 81 percent for cadmium.

Additional reductions will be realized when discharge from the Keystone blowout and seepage from the Upper Windy Camp portal are addressed.

2.5.2 Concentration Summary

Average annual dissolved copper, cadmium, and zinc concentrations for the sample location at the West Squaw Creek Bridge are summarized in Table 2-6 and are shown on Figures 2-24 through 2-26. The results on the table and figures show a significant downward trend since the initial WDRs were issued by the RWQCB in 1978, 25 years ago. The largest annual decline occurred when the main Weil portal was sealed between 1980 and 1982.

Based on the regression equation shown on each figure, dissolved copper has decreased from an average of 1,600 ug/l in 1978 to 140 ug/l in 2003. Similarly, dissolved zinc has decreased from 2,300 ug/l in 1978 to 360 ug/l in 2003, and dissolved cadmium has decreased from 15 ug/l in 1978 to 2.5 ug/l in 2003. These values represent a 92 percent decrease in copper, 84 percent decrease in zinc, and 83 percent decrease in cadmium.

2.5.3 Estimated Copper Concentration

An estimate of the average annual dissolved copper concentration in West Squaw Creek at the West Squaw Creek Bridge, after residual discharge from the Keystone Blowout and Upper Windy Camp portal is addressed, is presented in this section. This section has been added in response to a comment received on the February 2003 UAA, Draft Report.

The average dissolved copper loading entering Shasta Lake after residual discharge from the Keystone Blowout and Upper Windy Camp portal is addressed is estimated to be 16 lb/day dissolved copper (see Table 2-3). This value represents a 95 percent decrease over the pre-1980 loading of 305 lb/day, and 30 percent decrease over the current loading of 23 lb/day.

Assuming the average annual flow rate at the West Squaw Creek Bridge is 25,000 gpm (see Water Quality Appendix), and the dissolved copper concentration is constant, an average dissolved copper loading of 16 lb/day would yield a dissolved copper concentration of 50 ug/l. Typically, dissolved copper concentrations in excess of the average concentration are observed at the West Squaw Creek Bridge during low flow conditions in late summer and fall. Concentrations in excess of the average concentration will also be observed in West Squaw Creek tributaries that receive seepage from non-point sources.

Table 2-3
DISSOLVED COPPER LOADING SUMMARY
WEST SQUAW CREEK WATERSHED[1]

Location	Pre-Plug Loading[2] (lb/day)	Current Loading[3] (lb/day)	Current Percent Reduction	Anticipated 2004 Loading[4] (lb/day)	Anticipated 2004 Percent Reduction
Early Bird Portal	4.90	0.00	100	0.00	100
Main Keystone Portal	8.80	0.04	100	0.04	100
Keystone Blowout	0.00	2.24	---	0.02	99
Upper Windy Camp Portal	3.30	3.30	0	0.03	99
Lower Windy Camp (Balaklala 11) Portal	30.60	0.40	99	0.40	99
Main Weil Portal	227.00	0.00	100	0.00	100
Lower Shasta King Portal	5.36	2.68	50	1.34	75
Portal Total	280	9	97	2	99
Portal Percent	92	38	---	11	---
Non-Portal Total	25	14	43	14	43
Non-Portal Percent	8	62	---	89	---
West Squaw Total	305	23	92	16	95

Notes:
[1] See Water Quality Appendix for additional details such as number of samples, etc.
[2] Pre-Plug Loading represents mass loading prior to the installation of the bulkhead seals.
[3] Current Loading represents mass loading between 2000 and August 2003, except in the case of the Keystone portal where the treatment unit did not come online until 2001.
[4] Anticipated 2004 Loading represents estimated mass loading after treatment facilities for the Keystone blowout and Upper Windy Camp portal come online.

Table 2-4 DISSOLVED ZINC LOADING SUMMARY WEST SQUAW CREEK WATERSHED[1]					
Location	**Pre-Plug Loading[2] (lb/day)**	**Current Loading[3] (lb/day)**	**Current Percent Reduction**	**Anticipated 2004 Loading[4] (lb/day)**	**Anticipated 2004 Percent Reduction**
Early Bird Portal	2.70	0.00	100	0.00	100
Main Keystone Portal	11.30	7.52	33	2.63	77
Keystone Blowout	0.00	2.44	---	0.85	65
Upper Windy Camp Portal	6.42	6.42	0	2.25	65
Lower Windy Camp (Balaklala 11) Portal	41.10	0.70	98	0.70	98
Main Weil Portal	211.00	0.00	100	0.00	100
Lower Shasta King Portal	5.06	2.53	50	1.27	75
Portal Total	278	20	93	8	97
Portal Percent	68	15	---	6	---
Non-Portal Total	131	111	15	111	15
Non-Portal Percent	32	85	---	94	---
West Squaw Total	409	131	68	119	71

Notes:
[1] See Water Quality Appendix for additional details such as number of samples, etc.
[2] Pre-Plug Loading represents mass loading prior to the installation of the bulkhead seals.
[3] Current Loading represents mass loading between 2000 and August 2003, except in the case of the Keystone portal where the treatment unit did not come online until 2001.
[4] Anticipated 2004 Loading represents estimated mass loading after treatment facilities for the Keystone blowout and Upper Windy Camp portal come online.

Table 2-5
DISSOLVED CADMIUM LOADING SUMMARY
WEST SQUAW CREEK WATERSHED[1]

Location	Pre-Plug Loading[2] (lb/day)	Current Loading[3] (lb/day)	Current Percent Reduction	Anticipated 2004 Loading[4] (lb/day)	Anticipated 2004 Percent Reduction
Early Bird Portal	0.02	0.00	100	0.00	100
Main Keystone Portal	0.11	0.01	94	0.01	94
Keystone Blowout	0.00	0.02	---	0.00	99
Upper Windy Camp Portal	0.04	0.04	0	0.00	99
Lower Windy Camp (Balaklala 11) Portal	0.21	0.00	98	0.00	98
Main Weil Portal	1.20	0.00	100	0.00	100
Lower Shasta King Portal	0.03	0.02	50	0.01	75
Portal Total	1.60	0.09	95	0.02	99
Portal Percent	47	14	---	3	---
Non-Portal Total	1.80	0.55	69	0.55	69
Non-Portal Percent	53	86	---	97	---
West Squaw Total	3.40	0.64	81	0.57	83

Notes:
[1] See Water Quality Appendix for additional details such as number of samples, etc.
[2] Pre-Plug Loading represents mass loading prior to the installation of the bulkhead seals.
[3] Current Loading represents mass loading between 2000 and August 2003, except in the case of the Keystone portal where the treatment unit did not come online until 2001.
[4] Anticipated 2004 Loading represents estimated mass loading after treatment facilities for the Keystone blowout and Upper Windy Camp portal come online.

Table 2-6
CONCENTRATION SUMMARY[1]
WEST SQUAW CREEK BRIDGE

Year	Dissolved Cd		Dissolved Cu		Dissolved Zn		pH[2]	
	Number Samples	Average (ug/l)	Number Samples	Average (ug/l)	Number Samples	Average (ug/l)	Number Samples	Average
1968	0	---	12	2793	0	---	10	2.9
1969	0	---	21	1272	0	---	10	3.2
1972	Clean Water Act revised and expanded in 1972							
1974	1	11.0	1	2000	1	3800	2	3.2
1975	2	17.4	2	2875	2	3115	6	3.4
1978	RWQCB issued first permit to address ARD in 1978							
1980	8	16.6	8	3194	8	3513	2	3.5
1981	6	22.5	7	2864	7	3236	6	3.2
1982	21	5.0	23	661	23	827	22	4.0
1983	4	7.0	4	195	4	1060	5	4.9
1986	7	1.9	7	346	7	481	7	5.5
1988	4	3.1	4	545	4	728	4	4.6
1989	10	6.6	11	790	11	1200	11	4.4
1990	11	4.9	11	556	11	947	11	4.8
1991	14	6.9	15	640	14	1067	12	4.4
1992	13	3.7	14	459	14	750	12	5.0
1993	11	3.5	11	264	11	515	9	5.8
1994	14	4.7	16	441	16	842	12	5.0
1995	10	3.3	11	278	11	548	10	5.2
1996	7	2.1	7	278	7	427	7	4.7
1997	4	3.4	4	284	4	555	4	5.6
1998	4	2.5	4	253	4	375	4	5.4
1999	2	13.8	2	215	2	430	2	6.5
2000	4	4.3	4	275	4	661	4	6.7
2001	4	0.9	4	114	4	690	4	6.1
2002	5	1.6	5	86	5	626	5	6.5
2003[3]	9	1.4	6	17	9	221	7	6.3

Notes:
[1] See Water Quality Appendix for data tables.
[2] pH values were converted to hydrogen ion concentrations before calculating annual averages, then reconverted to pH
[3] 2003 copper average does not include three samples analyzed by MRRC at its in-house laboratory. If these results are included, the average dissolved copper concentration for 2003 is 11 ug/l.

SECTION 3

Physical and Biological Assessment

3.0 PHYSICAL AND BIOLOGICAL ASSESSMENT

In order to evaluate the potential of the West Squaw Creek watershed, Shepard Miller (1996a) conducted a literature review and field-sampling program to estimate 'natural' metal concentrations in undisturbed areas with exposed metal sulfide deposits. Additionally, MRRC contracted with the California Department of Fish and Game (DFG, 2001) to conduct a physical and biological assessment of West Squaw Creek. General background conditions at the site and the results of these surveys are presented in this section.

3.1 BACKGROUND CONDITIONS

The West Squaw Creek watershed encompasses approximately 14 square miles, and flows in an easterly direction into Shasta Lake. Approximately one mile upstream from Shasta Lake, West Squaw Creek divides into the North and South Forks, which drain 8 and 5 square miles, respectively. Historic mining activities occurred primarily along the South Fork.

The topography of the watershed is characterized by very steep, rocky slopes; few slopes are less than 35 degrees and slopes of 50 degrees or more are common. Elevations range from approximately 1,060 feet above mean sea level (MSL) at the confluence of West Squaw Creek with Shasta Lake, to 4,649 feet above MSL at East Shirt Peak, the highest point in the watershed. Numerous bluffs and cliffs can be encountered in the area, making travel difficult. Jeep and logging trails provide the main access routes

3.1.1 Climate and Vegetation

The climate of the area is typified by hot summers and cool, wet winters. At the higher elevations, significant snowfall can make roads impassable to vehicle traffic for extended periods. Daytime temperatures of 110 degrees are common from June through September, and higher temperatures have been observed. These high temperatures last for approximately two to three weeks and then are followed by a period where temperatures fluctuate around 95 degrees. By contrast, winter temperatures drop down below freezing at the higher elevations where snow is common. The average temperature from November to March is approximately 49 degrees. Precipitation in the area varies from about 55 inches at lower elevations to 80 inches at higher elevations. The mean annual precipitation based on the long-term data from a weather station at Shasta Dam is about 60 inches and is representative of precipitation that can be expected for the lower elevations of the West Squaw Creek watershed (NOAA, 1996). Most of the precipitation occurs between November and April, and snow is common at higher elevations between November and March. The elevations of the ridges defining the watershed divides average 3,500 feet above MSL. The sharp differences in elevation cause considerable local variation in temperature and precipitation.

Vegetation in the watershed varies with altitude. Chaparral, including dense stands of manzanita (*Arctostaphylos sp.*) and other brush species, predominate at the lower elevations near the streambed. Vegetation within the balance of the watershed include digger pine (*Pinus sabiniana*), ponderosa pine (*Pinus ponderosa*), sugar pine *(Pinus lambertiana*), Douglas fir (*Pseudotsuga taxifolia*), California black oak (*Quercus kelloggii*), canyon live oak (*Q. wislizenii),* and interior live oak (*Q. chrysolepis*). This portion of Northern California has a relatively high fire frequency return interval. Prior to intensive fire suppression that began in the early 1900s, the fire return interval for the area ranged from 7-11 years. Fires were numerous, but typically less than two acres in size, with the largest known historical fire being approximately 50 acres in size.

3.1.2 Geology

The watershed lies within the West Shasta Copper-Zinc District, and its geology has been described in detail by Kinkel et al., (1956). The upper reaches of the South Fork, upstream from mining activity, consist mainly of clastic shales and siltstones. The ore zone of the mining district is contained within the Balaklala rhyolite, which is composed of volcanic flows, breccia, and tuffs of Middle Devonian age. The ore bodies of the West Shasta Copper-Zinc District are mainly massive pyrite (FeS_2) with smaller amounts of chalcopyrite ($CuFeS_2$) and sphalerite (ZnS) with minor quantities of gold and silver.

The massive sulfide deposits in the West Shasta Copper-Zinc District occur as tabular lenses of ore. The lenses of ore are of submarine volcanic origin, having formed along a volcanic ridge by precipitation from submarine hot spring brines approximately 200 million years ago (Lindberg, 1985). Before post-mineral faulting, the largest such lens is estimated to have been 4,500 feet long, several hundred feet wide, and slightly more than 100 feet thick (Kinkel et al., 1956). Advanced weathering of these massive sulfides has produced extensive gossan deposits throughout the West Squaw Creek watershed.

Gossan outcrops are the oxidized caps over sulfide ore bodies from which the metal sulfides have been oxidized and partially leached by percolating ground waters, leaving a porous cap made up primarily of iron oxides and hydroxides, such as hematite (Fe_2O_3) and goethite ($FeOOH$), and quartz. Gossan outcrops in the region have been divided into two types: (1) massive gossan, derived from the weathering of massive sulfide ore, and (2) disseminated gossan, derived from the weathering of disseminated pyrite (Kinkel et al., 1956).

The soil mantle in this area is thin, discontinuous, and only partially developed. Numerous slump scarps reveal that landslides are common and have occurred in areas where slopes are steep. Landslide features that expose gossan rock to additional weathering increase the surface area for leaching of ARD.

3.1.3 Hydrology

The numerous small tributary streams to the South Fork of West Squaw Creek are generally intermittent. There are a number of springs along the canyon walls that maintain the base flow in West Squaw Creek. Most streams in the watershed are of a steep gradient and have been scoured to bedrock. These stream reaches have little vegetation and generally exhibit poor fish passage and lack habitat elements to support fish.

Groundwater movement in the area flows in a pattern typical in fractured impermeable rock. Water moves from the numerous small feeding fractures and fissures to large trunk channels furnished by larger fractures. Springs have developed where fractures intercept the surface. The mine workings have opened underground galleries in areas in which vadose water collects and discharges through mine tunnels and adits. The underground workings serve to provide both storage and interception galleries, which allow surface flow to percolate through the ground prior to discharge to West Squaw Creek.

Groundwater discharge into West Squaw Creek and its tributaries has a very low pH level due to its exposure with localized unoxidized sulfide deposits. Additionally, landslides and mass wasting of surface soils direct additional rock and soil into waterways and channels.

3.1.4 Geochemistry

Weathering of the sulfide minerals present in the West Shasta Copper-Zinc District produces acid-enriched and metal-enriched waters. Pyrite (FeS_2) is the most common metal-sulfide mineral in the massive sulfide deposits in the region, making up about 90 percent of the metallic mineral content. The remaining 10 percent of the sulfide deposits is primarily comprised of chalcopyrite ($CuFeS_2$) and sphalerite (ZnS). All of the metals and sulfur associated with these minerals are in a chemically reduced state; therefore, they are only stable in reducing conditions (reducing and oxidizing conditions as used here are relative terms that pertain to the availability of oxygen for chemical reactions). When exposed to the oxygen-rich atmosphere at the earth's surface, the natural response of the metals and sulfur in the minerals is to react with oxygen to achieve a more stable oxidized state. The presence of water enhances the rate of the reaction because it provides a medium where the transfer of reactants can take place. Under natural conditions, oxidation occurs where sulfide deposits are at or near the surface. In a mine, oxidation occurs when the once buried sulfide deposits are dewatered and exposed to air.

The oxidation of sulfide minerals occurs in a series of steps. In the first step, pyrite (FeS_2) reacts with oxygen and water to form ferrous iron (Fe^{2+}), sulfate (SO_4^{2-}) and acidity (H^+). In the second step, the ferrous iron reacts with oxygen and acidity to form ferric iron (Fe^{3+}) and water.

$$2FeS_2 + 7O_2 + 2H_2O \Longrightarrow 2Fe^{2+} + 4SO_4^{2-} + 4H^+ \qquad (1)$$

$$4Fe^{2+} + O_2 + 4H^+ \Longrightarrow 4Fe^{3+} + 2H_2O \qquad (2)$$

In the third step, because ferric iron is relatively insoluble under atmospheric conditions, a precipitation reaction takes place to form an iron oxide such as hematite (Fe_2O_3), or iron hydroxide such as goethite (FeOOH). Hematite and goethite are the primary components of the gossan deposits in the West Shasta Copper-Zinc District and around the world. An example of the formation of goethite is:

$$Fe^{3+} + 2H_2O \Longrightarrow FeOOH + 3H^+ \qquad (3)$$

Additionally, ferric iron may react with pyrite and water to form ferrous iron, sulfate and acidity. In this final reaction, it is important to note that the ferric iron, not oxygen, serves as the oxidizing agent.

$$FeS_2 + 14Fe^{3+} + 8H_2O \Longrightarrow 15Fe^{2+} + 2SO_4^{2-} + 4H^+ \qquad (4)$$

This reaction completes the cycle of transforming the primary component of massive sulfide deposits (pyrite) to a stable mineral under oxidizing conditions. The reaction results in the net production of sulfate and acidity. As mentioned, however, massive sulfide deposits generally include copper and zinc sulfides, such as chalcopyrite ($CuFeS_2$) and sphalerite (ZnS). These minerals oxidize to form copper and zinc sulfate, which are soluble and stable under acidic conditions.

Based on these reactions, it is easy to see that ARD remediation can focus on: (1) minimizing the production of metal sulfate by reducing the availability of oxygen and water, or (2) creating a reducing environment to convert soluble metal sulfate to less soluble metal sulfides. Installing bulkhead seals to flood the sulfide deposits is an example of the first approach, and constructing anaerobic wetlands to precipitate copper and zinc sulfide is an example of the second approach.

3.1.5 Physical and Chemical Weathering

Near-surface mineralized areas may be a source of natural contaminants to West Squaw Creek (Shepard Miller, 1996a). Such mineralization occurs in rocks that have been highly altered by hot fluids (hydrothermal fluids) that leave behind zones or veins of potential economically recoverable mineral deposits, within a halo of altered, strongly pyritic rock. The halo area may contain several percent pyrite (FeS_2) that, when weathered, generates sulfuric acid. Such acid causes more minerals and rock to dissolve, thus leading to high metal concentrations in surface waters. The combined activities of the metals and acid inhibit or preclude the formation of soil and vegetation, and the lack of soil cover protection leads to high erosion rates, relative to surrounding unmineralized areas. Such mineral processes and their environmental consequences are important because of the effects that they have on erosion rates and subsequent water quality.

The high percentage of mineralized areas in the West Squaw Creek drainage are affected by freeze-thaw cycles, downslope movement, and erosion of the steep slopes. Locally, these erosive processes, which serve to disaggregate the mineralized rocks at rates far in excess of the unmineralized rocks, are so extreme that soils have no chance to develop, or if developed locally, may be washed away by undercutting. The loss, or non-formation, of soil cover in addition to the steep terrain, promotes physical erosion at a much quicker rate and the release of sediments, acid, and dissolved metals to the surface waters cause water pollution.

Mining activities of the past at West Squaw Creek have also promoted the process of physical and chemical weathering by imposing on the natural cycle a man-induced component of physical weathering disaggregation. Rock dissaggregation, which results from blasting and crushing, exposes extra rock to chemical weathering by increasing the net surface area that is available to water and atmospheric oxygen. In disaggregated rock where surface area is high, a few percent of pyrite can cause pH, locally, to fall by several units.

3.2 STREAM SEGMENT IDENTIFICATION

The portion of the West Squaw Creek watershed from the Early Bird tributary to the mouth of West Squaw Creek at Shasta Lake (excluding the North Fork of West Squaw Creek) has been impacted by past mining activities. Overall, more than five miles of waterway on five separate stream segments are impacted. These segments are described in Table 3-1, and are shown in Figure 3-1.

A brief description of each segment, sources of ARD, and reduction in mass loading in response to remedial activities are summarized in this section. A more detailed water quality evaluation was presented in Section 2.

3.2.1 Segment EB

This segment includes the unnamed tributary near the Early Bird Mine. The segment includes approximately 4,500 feet of stream channel that feeds into West Squaw Creek. Steep slopes and rough terrain characterize the segment. The Early Bird Mine, including the Early Bird adit and waste rock pile, and a large disseminated gossan outcrop are located along the stream segment.

The Early Bird portal, located in the Early Bird drainage, was sealed in 1987. The seal resulted in a 100 percent decrease in copper loading and 100 percent decrease in zinc loading from the portal. Prior to sealing, approximately five lb/day copper and three lb/day zinc discharged from the Early Bird portal (Section 2).

3.2.2 Segment PA

This segment includes approximately 3,000 feet of stream channel that feeds into West Squaw Creek. Very steep slopes and inaccessible terrain characterize the segment. Massive and disseminated gossan outcrops are present along this tributary. The upper reaches of the watershed were disturbed by activities at the Keystone Mine.

3.2.3 Segment WIN

This segment includes all of Windy Creek, a tributary to West Squaw Creek. The segment includes approximately 4,500 feet of stream. The Windy Creek watershed has undergone significant disturbance due to past mining activities, specifically in the areas of the Keystone Mine and the Windy Camp ore body. Additionally, massive and disseminated gossan outcrops occur within the watershed.

Table 3-1 STREAM SEGMENT SUMMARY WEST SQUAW CREEK WATERSHED				
Stream Segment	Description	Stream Type	Total Length (feet)	Contributing Sources
EB	Unnamed tributary	Ephemeral	4,500	Early Bird Mine, including main portal and small waste rock pile, large disseminated gossan and massive gossan outcrops.
PA	Unnamed tributary	Ephemeral	3,000	Portion of Upper Keystone Mine and disseminated gossan outcrops.
WIN	Windy Creek	Perennial	4,500	Keystone Mine, including three keystone portals. Windy Camp ore body, including two portals, waste rock, and disseminated gossan outcrops.
WEIL	West Fork Weil tributary	Ephemeral	4,000	Weil ore body, including two portals, large waste rock pile and massive gossan outcrops.
WSC	West Squaw Creek between Early Bird tributary and Shasta Lake	Perennial	15,000	Previous four stream segments, Shasta King Mine, including main portal and waste rock piles, massive and disseminated gossan outcrops.

Three Keystone adits were sealed in 1992, and two Windy Camp portals, including Balaklala 11, were sealed in 1985. Overall, metal loading from point source discharges in this watershed have been reduced 75 percent from approximately 100 lb/day to 25 lb/day (Section 2). In addition to the bulkhead seals, the waste rock piles in this drainage have been graded and planted, and a 1,600 foot diversion channel was installed to convey flow in Upper Windy Creek around the Upper and Lower Windy Camp waste rock piles.

3.2.4 Segment WEIL

This segment includes the West Fork of the Weil tributary, a tributary to West Squaw Creek. The segment includes approximately 4,000 feet of stream channel. The watershed includes the Weil ore body, including the main Weil portal and waste rock pile. Massive gossan outcrops occur with the watershed. The Weil portal was sealed between 1980 and 1982. The seal resulted in a 100 percent reduction in copper loading and 100 percent reduction in zinc loading from the portal. Pre-plugging mass loading from the portal to the tributary was in excess of 400 lb/day (Section 2).

3.2.5 Segment WSC

This segment includes West Squaw Creek between the confluence of the Early Bird tributary and Shasta Lake. The segment is approximately 15,000 feet in length. This portion of West Squaw Creek receives drainage from the aforementioned tributaries and portals, Shasta King Mine, numerous waste rock piles, disseminated gossan outcrops, and massive gossan outcrops. It also receives drainage from the North

Fork of West Squaw Creek, Mary's Fork, and two unnamed tributaries. The Shasta King portal was plugged in 1989.

3.2.6 West Squaw Creek at the Bridge

Since remedial activities were initiated in 1978, point source discharges of ARD to West Squaw Creek have been reduced by 95 percent from 560 lb/day to 30 lb/day. Overall, point and nonpoint discharge, as measured at the West Squaw Creek bridge, has been reduced by 80 percent from 720 lb/day to 150 lb/day (Section 2). Even with these reductions, copper and zinc concentrations in West Squaw Creek at the bridge continue to be in violation of the water quality objectives identified in the Basin Plan to be protective of a warm and cold-water fishery.

3.3 PRE-MINING CONDITIONS

Runnels, et al., (1992) proposed three methods for estimating the natural background chemistry of water in mineralized areas:

- Examination of historical documents,
- Comparison of natural concentrations in unmined, mineralized areas,
- Geochemical modeling and bench scale studies.

In order to evaluate 'natural' conditions in the West Squaw Creek watershed, Shepard Miller (1996a) conducted an evaluation using Runnels methods. This evaluation illustrates that the numeric objectives in the Basin Plan for the protection of a warm and cold-water fisheries are unrealistic in areas with significant metal sulfide deposits.

3.3.1 Background Metal Concentrations in West Squaw Creek

The presence of gossan and other mineralized rock at the surface and in the shallow subsurface provides a naturally-occurring source of acidity and metals to surface and ground water. Gossans are the oxidized caps over sulfide ore bodies from which the metal sulfides have been oxidized and partially leached by percolating ground waters, leaving a porous cap made up primarily of quartz and iron oxyhydroxides (e.g., hematite, Fe_2O_3, and goethite, FeOOH). Gossan formations are common in the West Shasta Copper-Zinc District. They have been divided into two types: (1) massive gossans derived from the weathering of massive sulfide ore, and (2) disseminated gossan derived from the weathering of disseminated pyrite (Kinkel et. al, 1956).

Sanzolone and Domenico (1985) report concentrations of copper from 700 mg/kg (0.07 percent) to 3,000 mg/kg (0.3 percent) and zinc concentrations up to 500 mg/kg (0.05 percent) in seven samples of gossan from the Shasta King Mine. These concentrations are typical for gossan from other mines in the West Shasta Copper Zinc Mining District (Sanzolone and Domenico, 1985). Therefore, the fact that metal-bearing gossan is exposed along West Squaw Creek must be included in attempting to define the chemical conditions that existed in West Squaw Creek prior to mining.

Massive gossan and disseminated gossan rock outcrops are common on the hill slopes of West Squaw Creek. Outcrops mapped by Kinkel et al. (1956) were confirmed in April 1996 (Shepard Miller, 1996a) and are shown on Figure 3-1. Additional areas of disseminated gossan and gossan float were also identified and mapped in 1996. The gossan outcrops, which are composed primarily of hematite, goethite, and silica, vary from reddish-brown to blackish-brown in color, and display classic boxwork textures associated with massive sulfide weathering. Inspection of the gossan in portal entrances shows that small lenses of unoxidized sulfide minerals, primarily consisting of pyrite, exist within a few feet of the surface. In addition to outcroppings, several areas of disseminated gossan subcrop were identified from rock float littering the surface. All of these mineralized areas would have contributed natural acidity and metals loading to West Squaw Creek prior to mining.

The Early Bird portal is located within a large disseminated gossan outcrop which extends upslope from the mine for several hundred feet. The outcrop is approximately 10 percent to 30 percent gossan, with the remainder being less oxidized Balaklala rhyolite.

Massive gossan outcrops are also exposed at the Shasta King Mine, and the massive ore body itself is naturally exposed in the canyon wall (Kinkel et al., 1956). The massive gossan outcrops overlying the Shasta King Mine are composed of completely oxidized materials at the surface, but small lenses of unoxidized sulfide minerals, primarily consisting of pyrite, are observed within a few feet of the surface in portal entrances. Kinkel et al. (1956) also notes gossan outcrops to the southwest of the Shasta King on the opposite side of the West Squaw Creek canyon. Areas northwest of the Shasta King Mine are some of the best examples of disseminated gossan. The outcrop of the ore body has a length of 590 feet and a maximum thickness of 42 feet (Kinkel et al., 1956).

Massive gossan outcrops are also exposed in the vicinity of the Windy Camp ore body. These exposures show that the original sulfide deposits were leached to a depth of between 20 and 25 ft below the present-day ground surface. Uphill from the glory hole, gossan outcrops within the drainage between the Keystone Mine and Windy Camp ore body have up to 20 percent partially oxidized sulfide minerals exposed at the ground surface. An area northwest of the Keystone Mine is another excellent example of disseminated gossan identified in rock float material. Historically, drainage from these natural outcrops has flowed into Windy Creek, and then into West Squaw Creek. Some massive gossan also crops out near the Weil portal. Other gossan outcrops within the West Squaw Creek watershed are primarily derived from leaching of rhyolite bedrock containing 5 percent to 60 percent disseminated sulfide minerals.

The most highly mineralized areas in the West Squaw Creek watershed have been mined, with obvious disturbance to the surface. This makes it difficult to determine natural background water quality. However, water quality samples collected from non-mined areas in the watershed exhibit slightly elevated metals concentrations. For example, the copper and zinc concentrations in samples collected from West Squaw Creek upstream from all known mining activity and areas of mineralization were as high as 92 ug/l and 720 ug/l, respectively. Samples collected from the tributary that runs past the Early Bird portal were as high as 12 ug/l dissolved copper and 33 ug/l dissolved zinc. Concentrations on the tributary between the Shasta King Mine and the North Fork contained 23 ug/l dissolved copper and 45 ug/l dissolved zinc. The corresponding numeric water quality objectives in the Basin Plan are 5.6 ug/l for copper and 16.0 ug/l for zinc (Shepard Miller, 1996a). These data are included in the Water Quality Appendix.

3.3.2 Survey of Existing Literature Concerning Natural ARD

The determination of pre-mining background concentrations of acidity and metals in waters of mineralized districts is difficult due to the overprint of many years of mining activity. However, a literature review of natural background chemistry in other mineralized, non-mined areas gives a basis for an estimate of the natural background conditions of West Squaw Creek prior to mining (Shepard Miller, 1996a).

Many papers published in the scientific literature indicate that elevated copper and zinc concentrations are present in ground and surface waters near non-mined ore deposits similar to the massive sulfide deposits in the West Squaw Creek watershed. According to Runnells et al. (1992), non-acidic waters associated with metallic mineral deposits can have metal concentrations that are naturally three to four orders of magnitude higher than global averages for those metals in normal stream waters. Metal concentrations in naturally occurring acidic waters associated with metallic deposits are even higher. For example, natural seeps in apparently undisturbed areas within the West Shasta Copper-Zinc District (near the Mammoth Mine) contain concentrations of copper ranging from 63 to 2,600 ug/l and zinc ranging from 21 to 310 ug/l (RWQCB, 1992).

An extensive review of surface water metal concentrations associated with mineral deposits worldwide was previously conducted by Runnells et al. (1992). Upon reviewing more than 40 literature references it was concluded that stream waters associated with ore deposits that have not been mined can be naturally acidic, exhibiting pH values as low as 2.6. Dissolved copper concentrations in these surface waters range from <1.0 to 68,000 ug/l and dissolved zinc concentrations range from <1.0 to 272,000 ug/l.

Russian literature (Brodskii, 1964, and Goleva, 1977) contains a considerable amount of information regarding background metal concentrations in natural waters associated with ore deposits. A survey of metal concentrations in stream waters associated with undisturbed copper-pyrite deposits in Russia showed natural concentrations of copper from 2 to 2,500 ug/l and zinc from 6 to 5,000 ug/l. The lowest reported values (2.0 ug/l for copper and 6.0 ug/l for zinc) result from the high degree of dilution by fresh water in the Que River, one of the largest rivers in Siberia.

Based on published values for copper and zinc in natural waters from mineralized areas worldwide, the estimated natural pre-mining copper and zinc concentrations West Squaw Creek could have ranged from <1.0 to 68,000 ug/l for copper and 21 ug/l to 16,000 ug/l for zinc. The highest published value of zinc from undisturbed areas (272,000 ug/l, stream water from the Red Dog Deposit, Alaska; Runnells et al., 1992) is valid, but it appears to be unusually high when compared to zinc concentrations for most natural waters in mineralized areas. The next lowest value (16,000 ug/l, from a stream in the Northwest Territories, Canada) is therefore used as a conservative estimate in the background evaluation.

Again, the published values described above depict copper and zinc concentrations in waters adjacent to ore deposits that have not been mined. However, few non-mined deposits in the world today exhibit the large amounts of metal-bearing gossan, pyrite, and other sulfides that were exposed naturally in the West Squaw Creek watershed prior to mining. In most cases, the published concentrations of metals for undisturbed mineralized areas are probably lower than the concentrations that were naturally present in surface and ground water in the West Squaw Creek watershed prior to mining, especially during summer low-flow conditions.

3.3.3 Geochemical Modeling and Bench Scale Studies

MRRC, in conjunction with Stauffer Management Company, commissioned a study of natural releases from mineralized bedrock in the West Shasta Copper-Zinc District in 1996. The study was conducted at the Mammoth Mine, an area with geologic conditions similar to the West Squaw Creek watershed. The Mammoth Mine is located in the Little Backbone watershed, just north of the West Squaw Creek watershed (Shepard Miller, 1996b).

Areas of mineralized bedrock at the Mammoth Mine are composed of a siliceous porphyritic rhyolite, containing up to 25 percent sulfides. Generally, the sulfide content varies between five and ten percent. The sulfide minerals primarily occur as dispersed individual grains of pyrite, and in thin (1 mm to 4 mm) stringers or veinlets of pyrite and sphalerite. Occasional thin coatings of secondary chalcocite occur on pyrite/chalcopyrite grains. The rock is highly fractured and the spacing between fractures is generally between five inches and ten inches. Fractures are commonly coated with a thin veneer of yellow sulfate salts. Yellow sulfate salts also occur within the matrix of broken rocks away from obvious fracture surfaces, indicating that sulfide oxidation is not confined to fracture surfaces. Relatively thick (2 mm to 4 mm) accumulations of sulfate salts were observed along fractures within one outcrop of the mineralized bedrock indicating that preferential groundwater flow along specific fracture zones may occur in the area.

Leaching experiments were performed using deionized water to simulate the chemical evolution of fresh rainwater as it enters the subsurface and flows along bedrock fractures. In the laboratory, mineralized bedrock samples were coarsely broken along natural fractures using a hammer and anvil to form fragments 2 cm to 5 cm in diameter. The rock fragments were placed in 1-liter beakers and covered with water. The water-to-rock ratio was 0.5 to 1.0 by weight. During the experiments, the rock and water mixtures were gently agitated twice a day. The pH and conductivity of the mixtures were monitored periodically during the experiments, and final leachates were analyzed in the laboratory for electrical conductivity, oxidation reduction potential, and pH. Samples of the water were collected after seven days and submitted for dissolved iron, aluminum, copper, zinc, and sulfate concentrations.

The initial pH values ranged from 2.7 to 4.4, and the conductivity values ranged from 11.6 μmhos/cm to 1,750 μmhos/cm. The oxidation reduction potential indicated that the solutions were oxidizing. The low pH values and high conductivity values indicate that the highly soluble sulfate salts provide an immediate source of dissolved constituents and acidity. These results suggest that after prolonged dry periods, the dissolution of natural sulfate salts causes metal loading to increase rapidly in surface waters during early wet season storms.

The final leachate samples were moderately to strongly acidic and had elevated metal concentrations. The average concentrations were 5,620 ug/l copper and 4,970 ug/l zinc. The results suggest that groundwater in the vicinity of the mineralized bedrock may be naturally acidic and have elevated metal concentrations. (Shepard Miller, 1996b).

These experimental data are supported by the results of a study conducted by the RWQCB (1992). In 1992, RWQCB personnel collected water samples from several acidic seeps located in areas unaffected by past mining activities. The resulting copper concentrations ranged up to 2,600 ug/l and zinc concentrations ranged up to 310 ug/l.

The results of the MRRC and RWQCB studies are consistent with published data (Runnells et al., 1992) showing that background metal concentrations in seepage from mineralized regions will be significantly higher than concentrations in seepage from non-mineralized areas.

3.4 PHYSICAL HABITAT ASSESSMENT

In the fall of 1999, MRRC contracted with the DFG Aquatic Bioassessment Laboratory to conduct biological and physical habitat assessments in West Squaw Creek. The assessments took place in seven distinct sites referred to as reaches of West Squaw Creek. Two reaches in creeks not in the same drainage as West Squaw Creek were assessed as background reaches. Physical, chemical, and biological conditions of the stream were evaluated using the California Stream Bioassessment Procedure (CSBP) (Harrington, 1999) and USEPA Rapid Bioassessment Protocols (Barbour et al., 1999). The CSBP is a regional adaptation of the USEPA Rapid Bioassessment Protocol and is recognized by the USEPA as California's standardized bioassessment procedure (Davis et al., 1996). This section is summarized from the final DFG (2001) report. Chemical data presented in this section were collected by DFG as part of the physical assessment.

Physical habitat quality was assessed for each monitoring reach during field sampling using the following physical measurement parameters:

- Global Positioning System (GPS) coordinates,
- Elevation,
- Riffle gradient,
- Riffle width,
- Canopy cover,
- Substrate complexity,
- Substrate consolidation,
- Proportion of different substrate sizes.

The stream reaches were located in areas that would assess the influence of ARD on physical conditions and biological communities. Three background reaches were selected in the general area with physical attributes similar (although chemically different) to those of West Squaw Creek to represent biological communities that have not been impacted. These reaches represent the upper, middle, and lower watershed site conditions. The background reaches are valuable in the comparison assessment to define the impact ARD has had on West Squaw Creek water quality and other physical conditions of the streams. The background reaches discussed in this heading were selected and named by the DFG during assessment activities and do not directly correspond to the stream segments identified earlier in this section. The stream reaches are described in Table 3-2 and shown on Figure 3-3.

Physical habitat quality was assessed using USEPA's national standard scoring criteria. These criteria measure the physical integrity of a stream to determine if the stream can support life based on its physical condition. Scores range from 0 to 20 for each of the 10 specific habitat parameters and then the 10 are totaled for an overall score. The habitat evaluation includes: Epifaunal Substrate/Available Cover (colonization potential), Embeddedness (diversity of niche space), Velocity/Depth Regimes, Sediment Deposition, Channel Flow Status, Channel Alteration (normal stream pattern), Frequency of Riffles, Bank Stability, Vegetation Protection (stream bank and riparian), and Riparian Vegetative Zone Width. Each parameter is evaluated for individual reaches and scored according to condition categories. The descriptions of the categories are outlined in the Physical Habitat Quality Worksheet used by DFG. Once the reach is assessed and scored, the parameters are totaled and the overall physical habitat quality is quantified. The totals are rated excellent, good, or poor, depending on the total for that reach.

Measurements of physical habitat characteristics are used to describe riffle environments within stretches to help interpret biological data. Riffle length was determined at each chosen transect location within the stream reach and an estimated average riffle width and depth was determined along the length. The riffle velocity was measured using a Marsh McBirney digital flow meter, placing it in front of the three locations along the transect where biological samples were collected, and the readings were averaged. Using a densiometer at several locations along the riffle, the percent of the riffle surface that was covered by shade from streamside vegetation (canopy cover) was determined and averaged. A visual estimation determined the substrate complexity and embeddedness, and the percentage of each substrate category (fines, gravel, cobble, boulder, bedrock) was estimated. The consolidation of the streambed was estimated by kicking the substrate with the heel of a wader boot and noting whether it is loosely, moderately or tightly cemented. The gradient of the riffle was also measured using a stadia rod and hand-held level.

Ambient water chemistry was recorded at each site using a Yellow Springs Instruments (YSI 85) water quality meter. Recorded measurements included water temperature, dissolved oxygen, pH, and specific conductance. In addition, stream water at each sample location was collected and transported to Columbia Analytical Laboratory in Redding, California, and analyzed for heavy metals, alkalinity, hardness, specific conductivity, dissolved oxygen, and pH. Containers were completely filled to avoid atmospheric gas exchange.

3.4.1 Physical Habitat Assessment Overall Results

A Physical Habitat Quality Assessment evaluates a stream's ability to support life apart from the effect of water quality. A majority of the sites sampled received excellent physical habitat scores. No sites received less than a good rating. Scores ranged from 177 to 135. As referenced in Table 3-3, WSC-5 exhibited the lowest score, partially due to increased embeddedness and decreased channel flow. Consistency in physical habitat scores allowed comparison of reference (background) reaches to other sites in the study area. A descriptive evaluation is included in Table 3-4.

The chemical characteristics varied among reaches. In particular, pH levels ranged between 7.96 and 4.28. Lowest alkalinity and highest hardness levels were found in the more downstream sites of West Squaw Creek. Alkalinity and hardness ranged from 40 mg/l to <10 mg/l and 144 mg/l to 15 mg/l, respectively. Temperatures generally ranged from 18.7°C to 10.3°C, increasing in more downstream sites. Specific conductance ranged from 41 micromhos per centimeter (umhos/cm) to 455 umhos/cm.

Table 3-2 STREAM REACHES DFG BIOASSESSMENT	
Reach	**Description**
Spring Creek (SC-1) Background	Sample SC-1 was selected as a reference (background) site as being representative of the mid-watershed reference site for West Squaw Creek. SC-1 is located on a drainage south of the West Squaw Creek watershed which discharges directly into the Sacramento River. The sample site is located at the same elevation as samples WSC-2 and WSC-4 and similar flow and physical habitat characteristics are present.
Dry Creek (DC-1) Background	DC-1 is located on a drainage directly south of the West Squaw Creek watershed. This drainage discharges directly into Shasta Lake and was selected as being representative of the lower watershed reference site for West Squaw Creek. The sample site elevation is the same as sample locations WSC-3, WSC-5, WSC-6, and WSC-7. Physical habitat and upstream topography is similar to that of West Squaw Creek.
WSC-1 Background	Reach WSC-1, located above the confluence with the Early Bird Mine drainage, is upstream from any mining activity and is not located within an analyzed stream segment. WSC-1 represented the upper watershed reference site for the West Squaw Creek drainage.
WSC-2	Site WSC-2, taken below the confluence with the Early Bird Mine drainage, is within stream segment WSC-A. WSC- 2 assesses the impact of the Early Bird Mine on West Squaw Creek.
WSC-3	WSC-3 is within stream segment WSC-B, taken below the confluence with the Balaklala and Keystone portal discharges. WSC-3 assesses the impact of these portals to West Squaw Creek.
WSC-4	Site WSC-4 is located below the confluence with the Balaklala Mine. Weil adit drainage is located in the WSC-B segment. This site is representative of the impact on West Squaw Creek from the Weil portal.
WSC-5	WSC-5 is also located within the WSC-B stream segment. This sample location is below the Shasta King Mine area, and assesses the impact from this area on West Squaw Creek.
WSC-6	Site WSC-6 is located below the confluence with the North Fork of West Squaw Creek and within stream segment WSC-C. This site assesses the downstream impact from all mining activities and natural ARD occurrences.
WSC-7	WSC-7 is within stream segment WSC-C, located at the mouth of West Squaw Creek. This sample site assesses the impact from ARD in the entire watershed before entering Shasta Lake.

Results of heavy metal analysis at sites on West Squaw Creek revealed dissolved cadmium, copper, and zinc concentrations that are toxic to most aquatic organisms. Cadmium, copper, and zinc concentrations ranged between <5.0 ug/l and 38.0 ug/l, <10 ug/l and 2,390 ug/l, and <20 ug/l, and 6,020 ug/l respectively. Dissolved iron levels were greater than 100 ug/l at WSC-4, WSC-5, and WSC-6.

3.4.2 Physical Habitat Assessment Discussion

3.4.2.1 Physical and Chemical Characteristics on Biological Communities

Aquatic biological communities require a diversity of physical and chemical conditions to maintain species that are more sensitive, high species diversity, and species richness. In particular, high quality physical stream habitat must be present to support aquatic communities. The two reference streams in the surrounding area (DC-1 and SC-1) and the headwater sites exhibited a normal range of chemical characteristics and physical habitat for supporting more diverse biological communities. Although the assessments indicate that the physical habitat, temperatures and dissolved oxygen concentrations at all West Squaw Creek sites are within good to excellent ranges, high concentrations of heavy metals, low pH, high specific conductance, low alkalinity, and high hardness lead to degraded biotic condition at most of the sites within West Squaw Creek.

3.4.2.2 *Acid Rock Drainage*

There are typically three ways in which ARD can cause adverse effects on aquatic communities in receiving waters: acidification (lowering of pH), increased heavy metal concentrations in solution, and metal precipitation (Kelly, 1988; Clements, 1991; Niyogi et al., 1999). Analytical results for dissolved copper, cadmium, zinc and pH, collected during the bioassessment are included on Table 3-3.

3.4.2.3 *Acidification*

Organisms can be directly affected by decreases in pH. Results of this study suggest that acidification is contributing to the impact of the biological community in sites WSC-3 and WSC-4. Each of these sites approached a pH of 4.5, a level at which a fishery cannot be supported (McCormick, 1989). For most species, including Rainbow Trout (*Onchorhynchus mykiss*), toxic pH levels (<5.0) are similar to pH values in West Squaw Creek (Baker et al., 1990). Results of biological community analyses in this study were also consistent with previous studies on the effects of acidification on invertebrates. Recent studies have shown that dipterans tend to be more acid tolerant, whereas mayflies (*Ephemeroptera*) and caddisflies (*Trichoptera*) are more sensitive to lower pH levels (Sparling, 1995). Chironomid midges (*Diptera: Chironomidae*), found in abundance during this study, are particularly acid tolerant (Allard and Moreau, 1987). It is likely that the changes in pH in WSC-3 through WSC-5 may have also negatively affected periphyton communities. As pH becomes lower (more acidic), high concentrations of cadmium, copper, and zinc typically become less toxic to algae (Campbell and Stokes, 1985). Consequently, one would expect that at sites where pH is low, soluble metal concentrations are high, and acidophilic (acid tolerant) diatom species are abundant, pH may be considered the parameter most likely affecting the periphyton community structure.

Table 3-3
PHYSICAL HABITAT QUALITY SCORES AND METAL DATA
WEST SQUAW CREEK WATERSHED [1,2]

Habitat Parameter	SC-1	DC-1	WSC-1	WSC-2	WSC-3	WSC-4	WSC-5	WSC-6	WSC-7
Epifaunal Substrate	17	14	19	16	14	13	10	15	14
Embeddedness	16	16	17	18	19	19	5	17	17
Velocity/Depth Regimes	14	17	16	16	17	14	17	17	16
Sediment Deposition	16	16	17	16	17	17	12	14	16
Channel Flow	15	12	14	16	13	15	9	15	14
Channel Alteration	13	20	20	20	18	19	15	20	17
Riffle Frequency	15	16	18	18	16	18	14	18	17
Bank Vegetation	17	16	18	18	14	13	15	16	15
Bank Stability	17	17	18	17	19	20	20	20	16
Riparian Zone	15	20	20	20	20	20	18	20	19
Total Score	155	164	177	175	167	168	135	172	161
Physical Condition	Excel.	Excel.	Excel.	Excel.	Excel.	Excel.	Good	Excel.	Excel.
Diss. Copper (ug/l)	<10	<10	<10	<10	2180	2390	2250	694	156
Diss. Cadmium (ug/l)	<5	<5	<5	<5	34.5	35.1	34.2	12.5	<5
Diss. Zinc (ug/l)	<20	<20	<20	<20	4,650	4,790	4,650	1,780	613
pH (units)	7.96	7.63	7.89	7.77	4.93	4.64	4.78	6.35	7.07

Notes:
[1] Habitat Quality Scores range between 0 and 200, where 200 – 150 (Excellent), 150 – 100 (Good), 100 – 50 (Poor), 50 – 0 (Completely Degraded).
[2] Metal data from DFG study and do not include historic data or data collected by MRRC.

Table 3-4 PHYSICAL HABITAT ASSESSMENT REACH SPECIFIC RESULTS		
Reach	**Definition**	**Results**
Spring Creek Background	Mid-mainstream	This reach represented the mid-watershed reference site for West Squaw Creek. Chemical constituents of SC-1 were, based on other streams in the area, within ranges that would be expected. Heavy canopy, low riffle depth, and excellent habitat were determined. Stream flow was comparable to other sites. SC-1 had a physical habitat score of 155 (excellent).
Dry Creek Background	Directly before entering in Shasta Lake	This reach represented the lower watershed reference site for West Squaw Creek. Chemical analyses show normal ranges of all measured chemical constituents for the region. An excellent habitat score was calculated for this segment.
WSC-1 Background	Above confluence with Early Bird Mine drainage	This reach represented the upper watershed reference site for West Squaw Creek. An excellent physical habitat score was calculated for WSC-1. All chemical parameters measured were within normal ranges and temperature levels were the lowest of any reach. WSC-1 was extremely well shaded by tree canopy.
WSC-2	Below confluence with Early Bird Mine	Reach WSC-2 had an excellent physical habitat score and included heavy tree canopy, near neutral pH, low soluble heavy metal concentrations, and high buffering capacity. Flow was comparable to the background reach and was typical for the time of year.
WSC-3	Below confluence with Balaklala & Keystone portal drainage	Although physical habitat scores were comparable to WSC-1 and WSC-2, monitoring reach WSC-3 displayed major shifts in chemical concentrations. Large increases in soluble cadmium, copper, zinc, conductivity, and hardness concentrations were determined. In addition, soluble iron concentrations were detectable for the first time in West Squaw Creek. Alkalinity decreased to less than 10 mg/l and pH dropped to 4.97. WSC-3 had an excellent physical habitat score at 168.
WSC-4	Below confluence with Weil Adit drainage	The chemical and physical characteristics of WSC-4 were very similar to those of WSC-3. Heavy metal concentrations, conductivity, alkalinity, and hardness were nearly unchanged, as pH slightly increased. Water flow was comparable to other sites. WSC-4 had a physical habitat score of 168 (excellent).
WSC-5	Below confluence with Shasta King Mine waste area	Physical habitat received a good rating at reach WSC-5, scoring 135. Soluble metal concentrations and hardness were extremely high, while alkalinity remained low. Stream flow was comparable to other sites.
WSC-6	Below confluence with North Fork West Squaw Creek	Soluble metal concentrations and conductivity were high at WSC-6. The dissolved oxygen concentration was the lowest of any monitoring reach, while canopy cover increased to 60 percent and pH was close to neutral. Flow rates and temperature were also higher at this site. WSC-6 had an excellent physical habitat score at 172.
WSC-7	Mouth of creek above lake's high water mark	An excellent habitat score was calculated for reach WSC-7. Compared to the other reaches, soluble heavy metal concentrations, pH, alkalinity, and hardness levels showed signs of improvement. Flow was comparable to other sites.

3.4.2.4 Heavy Metal Toxicity

Biota in acidic aquatic systems can be negatively affected by increases in soluble heavy metals, carbon availability, and changes in acid neutralizing capabilities (Genter et al., 1987; Planas, 1996). Studies have shown that heavy metals become increasingly more soluble as pH decreases (Campbell and Stokes, 1985). This is evident at WSC-3 through WSC-5. The three most toxic chemicals measured, copper, cadmium and zinc are discussed below. Although important when analyzing metal toxicity, synergistic and antagonistic effects among different metals are not discussed here.

Dissolved cadmium levels reported in West Squaw Creek during this study were as high as 38 ug/l. Periphyton growth has been shown to be inhibited at 6 ug/l (Schafer et al., 1994). Reported 48-hr acute toxicity values for cadmium to invertebrates range from 7.0 to 34,600 ug/l (Giesy et al., 1977; Martin and Holdrich, 1986). Several studies report chronic effects of cadmium to fish at concentrations as low as 0.5 to 1.0 ug/l (Chapman, 1978). Chronic toxicity of cadmium to freshwater invertebrates has been reported as low as 0.5 to 1.0 ug/l (Chapman, 1978).

Copper concentrations in West Squaw Creek were >2,000 ug/l. Copper toxicity to aquatic organisms has been well documented (Horne and Goldman, 1994). Although USEPA recommends that the concentration of copper not exceed 2 ug/l in water with an average hardness of 100 mg/l as $CaCO_3$, adverse effects on aquatic organisms have been shown at levels far below this (Schafer et al., 1994). Acute toxicity values (48-hr LC_{50}) for freshwater invertebrates have been reported ranging from 5 ug/l to 5,300 ug/l (Laws, 1993).

Zinc concentrations at the downstream West Squaw Creek sites were in excess of 4,500 ug/l. High concentrations of zinc are extremely toxic to aquatic organisms (Horne and Goldman, 1994). The USEPA recommends that zinc concentrations not exceed 190 ug/l (Moore, 1991). Gensemer et al., (1993) determined that diatom growth may be inhibited at high (>100 ug/l) zinc concentrations and low pH.

3.4.2.5 Metal Precipitates

Heavy metal oxide precipitation and deposition (caused by metals dropping out of solution) can also adversely affect stream biota. McKnight and Feder (1984) found that the deposition of iron and aluminum hydroxides below the confluence of an acidic and neutral stream (e.g. WSC-5) had greater effects on periphyton and invertebrates than pH or dissolved metals. In addition to the direct toxic effects, metal precipitants can reduce the interstitial spaces between substrates that provide the majority of macroinvertebrate habitat in streams. Metal oxide deposition can also limit algal growth and colonization (Sheldon and Skelly, 1990).

3.5 BIOLOGICAL ASSESSMENT

In conjunction with the previously discussed physical assessment, DFG conducted biological assessments in the seven reaches of West Squaw Creek. Physical, chemical, and biological conditions of the stream were evaluated, using the CSBP (Harrington, 1999) and USEPA Rapid Bioassessment Protocols (Barbour et al., 1999).

Three communities of organisms, periphyton (attached algae), benthic macroinvertebrates (BMI) (relating to bottom dwellers), and fish, were collected to assess the biological conditions of the stream. Organisms from different trophic levels (organisms at different nutritional levels) respond to pollution in different ways, and analysis of multiple trophic levels provides a more complete analysis (Barbour et al., 1999).

Periphyton plays a central role in primary production, carbon fixation, and nutrient uptake in streams, providing a critical link between chemical-physical elements and the rest of the aquatic community (Lowe and Pan, 1996). BMIs are sensitive in varying degrees to a variety of physical and chemical impacts (Rosenberg and Resh; 1993, Karr and Chu, 1999). BMI communities can have diverse assemblages and individual species can inhabit a stream for months to several years (Merritt & Cummins, 1995). As secondary consumers, fish are sensitive to a variety of disturbances in stream systems. Previous research has determined toxic thresholds to fish of heavy metals (Lloyd, 1961), pH (USEPA 1980), and a variety of other pollutants associated with ARD (Laws, 1993).

The stream reaches were located in areas that would assess the influence of ARD to different stream sections and the result on the biological communities.

3.5.1 Field Sampling

3.5.1.1 Benthic Macroinvertebrates (BMI)

Riffle length was determined for each riffle and a random number table was used to establish a point within the upstream third of the riffle from which a transect was established perpendicular to the stream flow. Starting with the transect of the lowermost riffle, the BMI within a two square foot area was disturbed upstream of a 1 foot wide, 0.5 millimeter mesh D-frame kick net. Sampling of the benthos was performed by manually rubbing cobble and boulder substrates followed by 'kicking' the upper layers of substrate to dislodge any remaining invertebrates. Duration of sampling ranged from 60 to 120 seconds, depending on the amount of boulder and cobble-sized substrates that required rubbing by hand; more and larger substrates required more time to process. Three locations representing the habitats along the transect were sampled and combined into a composite sample (representing a six square foot area).

3.5.1.2 Periphyton

Periphyton were sampled within the BMI/benthos transects immediately prior to the BMI sampling. At each transect, 3 rocks of similar size (< 15 centimeters in diameter) were selected and removed from the stream. A 25 square centimeter section of algae was then gently removed using a bent handled toothbrush and rinsed into a clean white enamel pan. The material then was suctioned into a pipette. The material from all three rocks was composited into a watertight, unbreakable, wide-mouthed container with 3 to 5 drops of preservation solution.

3.5.1.3 Fish

When physically possible, fish species were sampled in each stream reach using a backpack electroshocker. Beginning with the most downstream riffle, one pass of the electroshocker was made over the entire reach, taking care to sample cover and shallow areas. The stunned fish were collected by a second crewmember with a dip net and held in a bucket of stream water until the reach was completely sampled. Collected fish were then identified as to species, and measured to the nearest centimeter.

3.5.2 Biological Assessment Overall Results

A total of 108 periphyton taxa (classifications) were identified during the Fall 1999 sampling event. Of these, 101 were diatoms (algae with salicified skeletons) (*Bacillariophyceae*) and seven were soft algae. Although the periphyton community was primarily dominated by the same few taxa at all sites (*Achnanthes lanceolata, Achnanthes minutissima*, *Eunotia exigua*, and *Eunotia praerupta)*, changes in community structure were evident. The only soft algae identified at monitoring reaches where pH was less than 6.3 were the acid tolerant *Ulothrix sp.* and *Mougeotia sp.* Many *Navicula spp., Pinnularia spp., Cymbella spp., Frustulia spp., Rhopalodia spp., Epithemia spp., and Cocconeis spp.* were also identified.

Although 113 BMI taxa were identified in the monitoring reaches sampled, the vast majority of these taxa were rarely found. The BMI communities at a majority of the sites were primarily dominated by a few disturbance-tolerant taxa. Dipterans (winged) from the midge family Orthocladiinae was by far the most dominant taxon identified. The Orthocladiinae made up greater than 30 percent of the organisms identified at most monitoring reaches. At a majority of monitoring reaches that were accessible to sampling equipment, fish were notably absent. Only the background reaches in other drainages (DC-1 and SC-1) and headwater site on West Squaw Creek contained any fish or amphibians. Rainbow trout

(*Oncorhynchus mykiss*) and Pacific giant salamander (*Dicamptodon ensatus*) were the dominant taxa at these sites.

3.5.3 Periphyton Community Metrics

3.5.3.1 Richness

Periphyton taxa richness ranged from a low of nine to a high of 37 (background reach) with most sites having between 20 and 25 taxa. Only two sites had 30 or more taxa.

3.5.3.2 Composition Measures

Percent dominant taxa varied between monitoring reaches. The highest percentage found was 69 in the background reaches, while the lowest was 11. A majority of the reaches ranged between 20 and 30 percent dominance. Shannon diversity values were relatively low, ranging from 1.3 to 2.9 (background reach). Most reaches were between 2.0 and 2.5.

3.5.3.3 Tolerance Measures

Percent intolerant and tolerant taxa varied greatly between monitoring reaches. Average percent intolerant taxa ranged from 21.4 to 0. Percent tolerant taxa ranged from 12.9 to 0. Average percent acidophilic species ranged from 82.9 to 1.1.

3.5.3.4 Community Comparison

Periphyton community similarity varied between sites. Similarity between consecutive monitoring reaches on West Squaw Creek ranged between 71 percent and 3 percent. WSC-5 displayed the lowest percentage of community similarities of any sites.

3.5.4 BMI Community Metrics

3.5.4.1 Richness

Average BMI taxa richness was extremely low for most monitoring reaches. Taxa richness ranged from a low of 2 to a high of 38 in background reach SC-1, with most sites having between 2 and 10 taxa. The relative EPT [*Ephemeroptera* (mayfly), *Plecoptera* (stonefly) and *Trichoptera* (Caddisfly) insect orders] taxa richness was also low, ranging from a score of 0 to 56 with the improved richness in the background reaches.

3.5.4.2 Composition Measures

In a majority of monitoring reaches, Shannon Diversity values were extremely low. Only headwater and reference sites had values greater than 1.5. Most sites ranged between 0.2 and 1.2, whereas background reaches presented values of 2.1 to 2.4. Scores ranged from 62 to 0. A majority of the reaches had greater than 40 percent dominance.

3.5.4.3 Tolerance Measures

Percent intolerant and tolerant taxa varied greatly between monitoring reaches. Average percent intolerant taxa ranged between 27 (background reach) and 0. A majority of sites had less than 10 percent intolerant taxa. No BMI community at any site was made up of greater than 4 percent tolerant organisms, excluding background.

3.5.4.4 Functional Feeding Groups

All of the Functional Feeding Groups were present within the entire project, but shredders were encountered rarely and in only a few sites. Collectors were by far the most dominant Functional Feeding Group encountered. Predators were highest in mid-reach sites, making up 61 percent to 2 percent of the BMIs collected. The percentage of filterers and grazers ranged between 38 and 0, both decreasing in more downstream sites.

3.5.4.5 Abundance

Although West Squaw Creek headwater sites (background reach) contained greater than 1,400 BMIs per sample, abundance was extremely low in other sites. A majority of the monitoring reaches contained <40 BMIs.

3.5.5 Reach Results

Monitoring reaches were delineated according to the methods described in the CSBP (Harrington, 1999). Monitoring reaches consisted of at least a five-riffle section of stream in which all riffles had similar gradient and substrate characteristics. Control reaches were located in the least impacted upper watershed areas on each creek. Two nearby streams (Spring and Dry Creeks) were sampled to represent mid-watershed and lower watershed areas, respectively. Reach results are summarized on Table 3-5 and are shown on Figure 3-4.

3.5.6 Discussion

The biological communities in all monitoring reaches downstream of WSC-2 showed signs of being severely affected by ARD. In all these downstream sites, the fish and macroinvertebrate communities had very low diversity or were entirely absent, and periphyton communities shifted toward acid-tolerant species.

Results from field sampling also suggest that West Squaw Creek does not currently support fish downstream of WSC-2. While fish communities were not sampled at enough sites to provide a complete picture of their distributions in all watersheds of the area, the available data from sampled sites is consistent with a complete loss of fish from the downstream reaches of West Squaw Creek.

The distinct shift in the periphyton community compositions of West Squaw Creek, toward dominance of acidophilic species is common in streams subject to ARD (Genter, 1995a). In addition, results of this study and previous studies show that *Achnanthes minutissima* often dominates periphyton communities in headwater sites (Stevenson et al., 1991, Vis et al., 1998) and in streams polluted by moderate concentrations of heavy metals (Kelly et al., 1995, Medley and Clements, 1998). However, the reduction in abundance of *A. minutissima* in the most heavily acidified and metals contaminated sites, suggests that a threshold was exceeded. The absence of pollution intolerant *Cymbella spp, Synedra spp*., and soft algae that are present in reference streams, provides additional evidence of the negative effects of ARD on West Squaw Creek. Although periphyton species diversity scores and taxa richness are somewhat unrevealing, these metrics have been shown to remain steady during acidic events, while acidophilic species take the place of other acid intolerant taxa (Planas et al., 1989).

3.5.7 Conclusions

There were major changes in all three biological communities at areas within West Squaw Creeks. Both the BMI and fish communities showed abrupt changes between WSC-2 and WSC-3 while algae were very effective at tracking the pH changes in the stream systems. Changes to the periphyton communities primarily involved community shifts to a community dominated by acidophilic species. The abrupt change in West Squaw Creek also followed the abrupt change in pH and metals in that stream.

The difference in responses of these trophic (nutritional) levels to ARD suggests that there was a quantitative response in the algae but a threshold response in both the fish and BMIs. These differences demonstrate the value of using multiple species assemblages to characterize the influence of disturbances like ARD. In this case, the algae responses can be reviewed to track the influence of the multiple inputs of ARD, while the BMI responses indicate the point at which the impacts affect higher trophic levels.

There seems to be a slight improvement in some of the biological measures at the downstream sites on West Squaw Creek. Acidophilic diatoms no longer dominate the periphyton community and there is a slight increase in macroinvertebrate taxa associated with an increase in the prevalence of grazing and filtering macroinvertebrates.

3.6 ENDANGERED SPECIES ACT (ESA)

3.6.1 Overview and Background

USEPA has final approval authority for Basin Plan amendments. USEPA's approval of new and revised state water quality standards is a federal action subject to the consultation requirements of Section 7(a)(2) of the Endangered Species Act (65 FR 24647 (April 27, 2000)). Section 7(a)(2) of the ESA states that:

> Each federal agency shall ensure that any action authorized, funded, or carried out by such agency is not likely to jeopardize the continued existence of any endangered or threatened species or result in destruction or adverse modification of designated critical habitat.

Although consultation under the ESA is USEPA's obligation, the USEPA and the states acknowledge that states can assist USEPA in fulfilling its ESA obligations, and have a role in assuring that state standards adequately protect aquatic life and the environment, including threatened and endangered species (65 FR 24643).

This section has been prepared to assist the USEPA in meeting its obligations under Section 7(a)(2) of the ESA as part of its action to approve the proposed Basin Plan amendments for West Squaw Creek.

3.6.2 California Department of Fish and Game

DFG has been a cooperator with the RWQCB in reviewing regulatory alternatives to address mine discharge in West Squaw Creek. DFG has been a party to all initial meetings and preparation of the first draft of the UAA. DFG continues to be involved in the regulatory process and the development of revised criteria for West Squaw Creek. DFG staff conducted the biological assessment presented in this document.

3.6.3 National Marine Fisheries Service (NMFS) ESA Considerations

NMFS has regulatory jurisdiction over anadromous fish, and is the agency responsible for listing steelhead as threatened under the federal ESA. Central Valley steelhead was listed as a federally listed species under the federal ESA (63 FR 13347 (March 19, 1998, effective May 18, 1998)). Subsequent to that listing, NMFS promulgated its Final Rule defining critical habitat for steelhead in the Central Valley of California "Evolutionary Significant Unit" on February 16, 2000 (65 FR 7764).

In promulgating the critical habitat designation, NMFS was clear to point out that the available information allowed it only to characterize "basin-level designations," and that it cannot yet "…*depict salmonid habitats in a consistent manner or at a fine geographic scale*…" (65 FR 7767). Consequently, although NMFS has stated its preference to identify critical habitat by designating specific areas accessible to the species within the range of hydrologic units within each evolutionary significant unit, the watershed-based description does not provide "…the level of resolution to define the species' presence or absence in specific local creeks and streams…" (65 FR 7767).

Preliminary discussions with NMFS indicate they do not believe they have an interest in the proposed action due to the location of the action behind Shasta Dam and lack of anadromous access to West Squaw Creek. NMFS did express an interest in the UAA process and desire to be included in the correspondence to develop better understanding of the UAA process.

3.6.4 U.S. Fish and Wildlife Service (USFWS) ESA Considerations

USFWS has regulatory jurisdiction over all species listed under the Federal ESA other than anadromous salmonids, which fall under the jurisdiction of NMFS. In the event that a listed plant, amphibian, reptile, or other species for which USFWS has jurisdiction were to use West Squaw Creek and/or its riparian corridor, USEPA's action of approving the proposed Basin Plan amendment would not adversely affect the species, based on the scientific information compiled and contained within this report. This is primarily because the proposed amendments would not affect creek hydrology, nor would they change water quality by magnitudes that could affect these organisms. The proposed changes to the beneficial use designations were cooperatively developed by the RWQCB, DFG, and MRRC to be protective of current beneficial uses of West Squaw Creek.

3.6.5 Summary of ESA Concerns

Under the ESA, it is illegal to "take" a listed species without a permit or other authorization 16 U.S.C. § 1538(a). There can be a "take" of a species through habitat modification only to the extent that such modification results in the actual killing or injury to a member of the species (*Babbitt v. Sweet Homes Chapter of Communities for a Greater Oregon*, 515 U.S. 687 (1995)). Because approval and implementation of the proposed action modification to beneficial uses would not cause a change in the hydrology or water quality of West Squaw Creek, relative to existing conditions, such approval and implementation would not cause or increase the risk for "take" of endangered species that may use the waters of West Squaw Creek.

Table 3-5 BIOLOGICAL ASSESSMENT REACH SPECIFIC RESULTS		
Reach	**Definition**	**Results**
Spring Creek Background	Mid-mainstream	Periphyton species diversity at SC-1 was extremely high (Shannon Index 2.9). *Achnanthes lanceolata* was the most dominant periphyton taxon, making up 27 percent of the total organisms collected. A low percentage (8.6) of acidophilic diatom species was also determined. Unlike LBC and WSC periphyton communities, soft algae were present in SC-1. Green algae *Spirogyra* sp. and cyanobacteria *Oscillitoria* sp. were also identified. The BMI community in the Spring Creek reference reach (SC-1) displayed typical characteristics of a healthy stream. Compared to a majority of the sites on West Squaw Creek, SC-1 had high taxa richness (38), low percentage of dominant taxa (20), high EPT index (56), high species diversity (2.9), and a high abundance of intolerant organisms (27). In addition, Pacific Giant Salamanders (*Dicamptodon ensatus*) and Rainbow Trout (*Oncorhynchus mykiss*) were observed.
Dry Creek Background	Directly before entering into Shasta Lake	High periphyton species diversity (2.4), high taxa richness (35) and a high percentage of intolerant species (19) was observed within the Dry Creek reference reach (DC-1). Nearly no acidophilic species (2.9) were identified at DC-1. The soft algae *Spirogyra* sp. and *Scenedesmus* sp. were also identified. High BMI abundance (2372) and taxa richness (28) were observed at DC-1, while a lower than average percentage (34) of the dominant taxa Orthocladiinae (*Diptera: Chironomidae*) was calculated. High species diversity (2.4) was also observed. Abundance and diversity of fish was higher at the Dry Creek site than all other sites.
WSC-1 Background	Above confluence with Early Bird Mine drainage	The periphyton community at WSC-1 was the most diverse (2.6) of any site in West Squaw Creek. In addition, taxa richness (28) was higher than other sites. Percent of acidophilic species (18) was unusually high at WSC-1, while dominant taxon *Achnanthes sp #1* made up 17 percent of all diatoms identified. No soft algae were observed at WSC-1. The BMI community was also diverse (2.7) and contained a large number of taxa (38). Nearly 25 percent of the BMIs identified were pollution intolerant taxa. Compared to more downstream sites, percent EPT (40) and total abundance (1447) were higher, while percent dominant taxa (28) were lower. Rainbow Trout (*Oncorhynchus mykiss*) were also found at WSC-1.

Table 3-5 (continued) **BIOLOGICAL ASSESSMENT** **REACH SPECIFIC RESULTS**		
WSC-2	Below confluence with Early Bird Mine	Compared to WSC-1, diatom taxa richness (23) and species diversity (2.0) decreased at WSC-2, while percent dominant taxa increased to 34 percent and percentage of acidophilic species (1.3) decreased to nearly zero. *Achnanthes sp #1* and *A. lanceolata* were the most dominant taxa found in WSC-2. Soft algae *Spirogyra sp.* and *Scenedesmus sp.* were identified. The BMI community had an abundance of organisms (2145), moderate diversity (2.5), and a high percentage of intolerant species (22). Percent dominant taxa (25) and percent EPT (45) were very similar to WSC-1. Rainbow trout and Pacific Giant Salamanders were also present at WSC-2.
WSC-3	Below confluence with Balaklala & Keystone portal drainage	Compared to WSC-1 and 2, WSC-3 displayed drastic changes in periphyton structure. Acidophilic diatom species made up 64 percent of the periphyton identified. WSC-3 had low taxa richness (20), high percent dominant taxa (30), and moderate species diversity (2.2). Diatom *Eunotia exigua* made up 29 percent of the total periphyton identified. The acid tolerant soft algae *Ulothrix sp.* was identified. A total of 18 BMIs were found at WSC-3. Compared to WSC-2, species diversity (1.0), taxa richness (5), percent EPT (2), and percent intolerant taxa (1) drastically decreased. In addition, percent dominant taxa (60) increased. No fish were identified at this site.
WSC-4	Below confluence with Weil Adit drainage	Compared to WSC-3, diatom taxa richness (37) increased at WSC-4. A decrease in the relative abundance of acidophilic species (31) was also determined. Species diversity (2.2) remained unchanged. A shift in dominant taxa (20) to *A. lanceolata* was apparent, while filamentous soft algae *Ulothrix sp*. and *Microspora sp.* were also identified BMI taxa richness (2), species diversity (0.3), percent EPT (0), and percent intolerant species (0) were extremely low in WSC-4. Six organisms were collected for the entire reach. No fish were observed at this site.
WSC-5	Below confluence with Shasta King Mine waste area	A high percent acidophilic diatoms (75 percent) and percent dominant taxa (25) were found at WSC-5. The diatom *Eunotia praerupta* was identified as the dominant taxon. Compared to WSC-4, taxa richness (27), species diversity (2.0), and percent intolerant species (0) decreased. Filamentous soft alga *Ulothrix sp*. was also observed. Like the two previous monitoring reaches, site WSC-5 was characterized by a low abundance of BMIs (9), while species diversity (0.3) and taxa richness (2) remained extremely low. Percent dominant taxa (91) were extremely high. No fish were observed at this site.

Table 3-5 (continued) BIOLOGICAL ASSESSMENT REACH SPECIFIC RESULTS		
WSC-6	Below confluence with North Fork West Squaw Creek	Extremely, low periphyton species diversity (1.5) and taxa richness (9) were determined at WSC-6, while percent acidophilic species (57) was high. *A. minutissima* dominated the substrate, making up 57 percent of the organisms identified. No intolerant diatom species or soft algae were observed. BMI taxa richness (6) and percent EPT (0) remained extremely low. Compared to WSC-5, minor increases in species diversity (1.5) and total abundance (19) were observed, while the percent dominant taxa decreased (40). This site was not accessible for fish sampling.
WSC-7	Mouth of Creek above lake's high water mark	Analysis of the periphyton community determined the lowest species diversity (1.3) of any monitoring reach. *Achnanthes minutissima* again dominated the substrate, making up 69 percent of the frustules identified. Compared to WSC-6, taxa richness (22) and percent dominant taxa (67) increased, while percent acidophilic species (1.1) decreased. The soft algae *Spirogyra sp.* and *Vaucheria sp.* were also identified. BMI taxa richness (3), species diversity (1.0), and percent intolerant species (0) were low at WSC-7. Only 3 BMIs were collected at WSC-7. This site was not accessible to fish sampling equipment.

SECTION 4

Proposed Basin Plan Action

4.0 PROPOSED BASIN PLAN ACTION

This UAA is being prepared to support a Basin Plan Amendment for adoption by the RWQCB to modify the designated beneficial use of warm and cold freshwater habitat (WARM and COLD) to exclude fish and other metal or pH sensitive aquatic species, and to remove the designated, but not existing, beneficial use of warm and cold water spawning (SPWN) in West Squaw Creek from the Early Bird (EB) tributary to Shasta Lake. This West Squaw Creek stream segment is shown on Figure 4-1.

The actual change in the Basin Plan will be to specifically identify the beneficial uses of the identified segment of West Squaw Creek in Table II-1 of the Basin Plan, as shown on the following page.

Table III-1 of the Basin Plan will also be modified to reflect the change in beneficial uses. The maximum cadmium, copper and zinc concentrations listed on Table III-1 currently apply to the Sacramento River and its tributaries above State Hwy 32 Bridge at Hamilton City. The application of these standards will be modified to apply to Sacramento River and its tributaries above State Hwy 32 Bridge at Hamilton City, except for West Squaw Creek from the Early Bird (EB) tributary to Shasta Lake.

Table 4-1
SURFACE WATER BODIES AND BENEFICIAL USES

			MUN	Agriculture		Industry			Recreation			Freshwater		Migration		Spawning		WILD	NAV
				AGR		PROC	IND	POW	REC-1		REC-2	WARM	COLD	MIGR		SPWN			
	Surface Water Bodies (1)	Hydro Unit Number	Municipal and Domestic Supply	Irrigation	Stock Watering	Process	Service Supply	Power	Contact	Canoeing (1) and Rafting	Other Noncontact	Warm	Cold	Warm (3)	Cold (4)	Warm (3)	Cold (4)	Wildlife Habitat	Navigation
1	McCloud River	505.	E					E	E	P	E		E				E	E	
2	Goose Lake	527.20		E	E				E		E	E	E					E	
	Pit River																		
3	North Fork, South Fork, Pit River	526.00	E	E	E				E	P	E	E	E			E	E	E	
4	Confluence of Forks to Hat Creek	526.35	E	E	E			E	E	E	E	E	E			E		E	
5	Fall River	526.41	E	E	E			E	E	E	E	E	E					E	
6	Hat Creek	526.30		E				E	E		E	E	E				E	E	
7	Baum Lake	526.34						E	E		E		E				P	E	
8	Mouth of Hat Creek to Shasta Lake	526.	E	E	E			E	E	E	E	P	E			E	E	E	
	Sacramento River																		
9	Source to Box Canyon Reservoir	525.22		E	E				E		E		E					E	
10	Lake Siskiyou	525.22							E		E	E	E				P	E	
11	Box Canyon Dam to Shasta Lake	525.2		E	E				E	E	E		E				E	E	
12	Shasta Lake	506.10	E	E				E	E		E	E	E			E	E	E	
12(a)	West Squaw Creek		E	E				E	E		E	E (A)	E (A)					E	
13	Shasta Dam to Colusa Basin Drain		E	E	E		E	E	E	E	E	E	E	E	E	E	E	E	E
14	Whiskeytown Reservoir	524.61	E	E	E			E	E		E	E	E			E		E	
15	Clear Creek below Whiskeytown Reservoir	524.62	E	E	E				E	E	E	E	E		E	E	E	E	
16	Cow Creek	507.3	P	E	E			E	E	P	E		E		E	E	E	E	
17	Battle Creek	507.12		E	E			E	E	E	E	E	E		E	E	E	E	
18	Cottonwood Creek	524.3	E	E	E	P	P	P	E	E	E	E	E		E	E	E	E	
19	Antelope Creek	509.63	E	E	E				E		E	E	E		E	E	E	E	
20	Mill Creek	509.42	E	E	E				E		E	E	E		E	E	E	E	
21	Thomes Creek	523.10		E	E			P	E		E	E	E		E	E	E	E	
22	Deer Creek	509.20	E	E	E				E	E	E	E	E		E	E	E	E	
23	Big Chico Creek	509.14		E	E				E	E	E	E	E		E	E	E	E	
24	Stony Creek	522.00		E	E				E	E	E	E	P		E	E	E	E	
25	East Park Reservoir	522.33							E		E	E	P			E		E	
26	Black Butte Reservoir	522.12		E	E				E		E	E				E		E	
	Butte Creek																		
27	Sources to Chico	521.30	E	E	E			E	E			E	E		E	E	E	E	
28	Below Chico, including Butte Slough	520.40		E	E				E	E		E	E		E	E		E	
29	Colusa Basin Drain	520.21		E	E				E	E		E	P	E		E		E	

Legend:
E = Existing Beneficial Uses
P = Potential Beneficial Uses
L = Existing Limited Beneficial Use
A = Cold and Warm Freshwater Habitat does not include fish and other metal or pH sensitive aquatic species in West Squaw Creek from the Early Bird tributary to Shasta Lake.

Notes:
(1) Shown for streams and rivers only with the implication that certain flows are required for this beneficial use.
(3) Striped bass, sturgeon, and shad.
(4) Salmon and steelhead.

SECTION 5
Alternatives Evaluation

5.0 ALTERNATIVES EVALUATION

This section summarizes BAT and BMP remedial alternatives that have been considered by the RWQCB and MRRC to address ARD in the West Squaw Creek watershed. These alternatives are reviewed in this section for effectiveness, implementation, and cost. For the purposes of this evaluation, point source BAT and nonpoint source BMPs, are collectively referred to as BMPs.

A list of commonly used mine BMPs is shown below. These BMPs are divided into hydrologic controls, passive treatment, and active treatment. Often, incorporation of only one BMP will solve a particular problem. Sometimes, several BMPs must be incorporated. A practical summary of BMPs for sulfide mines is presented in a publication by the Colorado Division of Minerals and Geology (2002), "Best Practices in Abandoned Mine Land Reclamation: the remediation of past mining activities". A more generic evaluation of mining BMPs is presented in the "Abandoned Mine Site Characterization and Cleanup Handbook (USEPA, 2000). A BMP flow diagram is also included in the Basin Plan (SWRCB, 1979).

Hydrologic controls are generally considered preventive measures, as the goal of these BMPs is to inhibit acid formation or heavy metal dissolution. If hydrologic controls minimize or eliminate water from entering the mine or coming into contact with sulfide rocks, waste rock or tailings, they may eliminate the cause of the problem. For the purpose of this evaluation, bulkhead seals are included as a hydrologic control because they (1) reduce portal discharge and (2) minimize acid formation and heavy metal dissolution by flooding the mine workings.

Passive treatment generally refers to a range of treatment techniques that do not require continuous electrical or chemical inputs or frequent maintenance. In contrast, active treatment generally requires power and frequent maintenance. Treatment does not eliminate the cause of the problem, but in many cases, may be the only feasible alternative to address the problem.

- Hydrologic Controls
  - Bulkhead Seals
  - Diversion Ditches
  - Stream Diversion
  - Waste Rock/Tailings Removal and Consolidation
  - Erosion and Infiltration Control by Grading
  - Revegetation
  - Capping

- Passive Treatment
  - Aeration and Settling Ponds
  - Sulfate Reducing Wetlands
  - Oxidation Wetlands
  - Other Innovative BMPs to Treat ARD

- Active Treatment
  - Lime Neutralization

Table 5-1 REMEDIAL ALTERNATIVES SUMMARY WEST SQUAW CREEK WATERSHED						
Alternative	Early Bird	Keystone	Upper Windy Camp[1]	Lower Windy Camp[1]	Weil	Shasta King
Bulkhead Seal	✓	✓	✓	✓	✓	✓
Clear Water Diversion		✓				
Stream Diversion			✓	✓		
Waste Rock Removal				✓		
Waste Rock Grading		✓	✓			
Waste Rock Revegetation		✓	✓			
Capping		✓	✓			
Waste Rock Revegetation		✓	✓			
SRB Wetland Cell		✓				
Anoxic Limestone Drain			✓			
Limestone Injection		✓				

Note:
[1] Keystone Mine and Upper Windy Camp ore body were the most disturbed mining areas.

As summarized in Table 5-1, remedial actions at the West Squaw Creek mines have focused primarily on hydrologic controls to minimize the production of ARD. Where necessary, passive treatment alternatives have also been employed to reduce residual ARD contamination. In general, these activities were implemented in accordance with a feasibility study prepared by MRRC (Adrian Brown Consultants, 1997).

The impact of these remedial activities on ARD in West Squaw Creek was discussed, tabulated and graphed in Section 2. The reduction in metal loading, as presented in Section 2, is summarized in Table 5-2. Overall, the results show a significant decrease in metal loading following the completion of the remedial activities. Estimated mass loading at the West Squaw Creek bridge, after residual discharge from the Keystone blowout and the Upper Windy Camp portal is addressed are 16 lb/day for dissolved copper, 119 lb/day for dissolved zinc, and 0.6 lb/day for dissolved cadmium. As shown, the majority of the residual ARD is related to nonpoint sources. Estimated nonpoint contributions from each stream segment to the residual copper loading observed at the West Squaw Creek bridge are presented in Table 5-3.

5.1 RECLAMATION OF UNDERGROUND MINE WORKINGS

5.1.1 Bulkhead Seals

Bulkhead or portal seals are designed to reduce the flow of ARD and reduce the availability of oxygen by flooding the underground metal sulfide deposits. The principle problem with the use of bulkhead seals is ensuring their long-term integrity. Often, seals are required to withstand significant forces. In addition, the effectiveness of a seal may be reduced by flow through fractures in the surrounding rock. When a portal is sealed and the mine fills with water, ARD may exit the mine complex from other mine entries or through rock fractures. As the pressure in the mine increases, the competence of the formations within the mine may be reduced, sometimes resulting in increased leakage from the mine. MRRC has installed eight bulkhead seals to address ARD in the West Squaw Creek watershed.

Table 5-2 PRE VERSUS POST-REMEDIATION WEST SQUAW CREEK WATERSHED			
Location	**Dissolved Copper**	**Dissolved Zinc**	**Dissolved Cadmium**
Percent Reduction (pre to post-remediation)[1]			
Early Bird Portal	100	100	100
Main Keystone Portal	100	77	94
Keystone Blowout	99	65	99
Upper Windy Camp Portal	99	65	99
Lower Windy Camp (Balaklala 11) Portal	99	98	98
Main Weil Portal	100	100	100
Lower Shasta King Portal	75	75	75
Residual Point Source Mass Loading (lb/day)			
Point Source Total	1.84	7.70	0.02
Residual Mass Loading West Squaw Creek Bridge (lb/day)			
Bridge Total	16.18	119.09	0.57
Estimated Residual Nonpoint Source Mass Loading (lb/day)			
Nonpoint Source Total	14.34	111.39	0.55

Note:
[1] Percent reduction based on last column in Tables 2-3 through 2-5 in Section 2.

Table 5-3 RESIDUAL SOURCES OF DISSOLVED COPPER WEST SQUAW CREEK WATERSHED			
Location	**2004 Residual Copper Loading (lb/day)**	**2004 Residual Loading as Percent Loading at Bridge**	**2004 Residual Loading as Percent Pre-Remediation Loading**
Point Source Total[1]	2	12	<1
Nonpoint Weil Segment	2	12	<1
Nonpoint Windy Segment	8	50	2.6
Nonpoint Early Bird	1	6	<1
Nonpoint Shasta King	3	19	<1
Nonpoint Source Total[1]	14	88	5
Total at Bridge	16	100	5

Note:
[1] Point (2 lb/day) and nonpoint (14 lb/day) are based on information summarized in Table 5-2 and discussed in Section 2. The breakdown between nonpoint sources is based on downstream data from Windy Creek and preliminary continuous recorder data from the Weil tributary.

5.1.2 Mine Backfilling

Materials may be injected into mine workings (backfilled) in order reduce or eliminate the formation of ARD. Backfilling methods that have been considered include mine plugging, injection of neutralizing material, and injection of organic matter.

5.1.2.1 Mine Plugging

Filling underground mine voids with relatively low-permeability materials has been shown to be a promising method to reduce ARD by limiting sulfide exposure to water and air. Since underground mine workings can be extensive, the fill material and injection method must have low unit acquisition cost and a low unit placement cost. Costs may vary based on the nature and availability of fill material, access to the mine area, and the method of emplacement. Typical costs for easily accessible areas average $10 to $20 per ton material emplaced.

5.1.2.2 Injection of Neutralizing Materials

Injection of neutralizing materials into mine workings has the potential to reduce the generation of ARD by plugging the mine, and by neutralizing ARD where it is generated. The cost of injecting neutralizing material into mine working varies widely based on terrain (accessibility) and the type of material injected. The costs can be estimated to be in the order of $250 per ton of material. MRRC injected limestone into the main Keystone adit, behind the externally placed bulkhead seal, in 1998. The limestone did not significantly improve the quality of the discharge.

5.1.2.3 Injection of Organic Matter

Preventing the interaction of oxygen with pyrite in mine workings can effectively minimize ARD generation. Recent bench scale experiments have shown that organic materials placed in a mine may reduce the formation of ARD by limiting the presence of oxygen within the mine workings. Organic materials; such as manure, vegetable matter, or sludge, placed in mine workings; are decomposed by microorganisms that consume dissolved oxygen. As the dissolved oxygen concentration in the mine water decreases, sulfate-reducing bacteria convert soluble metal sulfates to less soluble metal sulfides. MRRC is conducting a pilot scale organic injection project in a nearby watershed. The cost of injecting the organic matter has been estimated to be $150 per ton of material injected.

5.2 SURFACE WATER CONTROLS

The volume of ARD generated by mine workings and waste rock piles can be decreased substantially by preventing mixing of unaffected surface water with ARD sources. The most common method of preventing such mixing is to divert surface water away from waste rock piles and areas where infiltration may occur into the mine workings.

Results of surface water diversions vary greatly based on the condition of mine workings, volumes of rainfall to be managed, permeability of materials, steepness of slopes, and reactivity of the waste rock. Under most conditions, surface water diversions are an effective abatement measure Diversion channels are subject to blockage and require routine maintenance.

Diversion channels are typically used to direct clean water flows away from mines and mine wastes in order to avoid contact between unaffected water and ARD. Construction methods include concrete channels, flexible-lined channels, steel-lined channels, and gabion-lined channels.

5.3 RECLAMATION OF WASTE ROCK

Objectives for reconfiguring waste rock piles include:

- Prevent contact between surface water and waste rock material,
- Decrease sulfide oxidation by limiting infiltration of water,
- Prevent erosion.

Reclamation of waste rock generally consists of regrading slopes, covering waste rock with materials to prevent water from contacting the rock and establishing vegetation. Other waste rock reclamation techniques include chemical surface stabilization and chemical amendments to the rock. The introduction of experimental bacteria applications has also been considered.

5.3.1 Regrading Waste Rock

Consolidating, moving and regrading waste rock material can minimize generation of ARD by reducing contact between sulfides, water and air; and can prevent erosion by producing a more stable hillside. In some locations, diverting surface water around a waste pile is more practical than moving the waste pile. However, if there is significant seepage from a pile or if waste material abuts a large stream, moving part or all of the pile may be considered. Waste material can be moved to an area that is located "high and dry" where practical, although in the project area there are relatively few locations where this is practicable for large material volumes. Retention structures may be placed at the bottom of waste rock piles to create a more stable pile and to collect and retain sediment eroded from the pile.

The cost of moving and regrading waste rock generally ranges from $5 to $10 per ton, although the cost at steep or remote locations may substantially exceed this range. In addition, estimation of the quantity of material present in waste piles is subject to error, particularly underestimation, due to the lack of information about the original surface on which the rock was disposed, and lack of information about the extent to which subgrade excavation will be required. Experience in reclamation projects in the project area and elsewhere is that the volumes of material which require removal are frequently under-estimated by as much as 100 percent. As the estimated volumes of waste rock material at the minesites are generally large, and the actual material to be moved are often prove to be much larger than the estimates, removal strategies rarely prove to be cost-effective. MRRC consolidated, moved and capped approximately 35,000 cubic yards of waste rock in a nearby watershed for approximately $35 per cubic yard.

5.3.2 Vegetation of Waste Rock Piles

Vegetating waste rock areas improves the aesthetic appeal of an inactive mine site, and improve overall water quality by reducing erosion of the waste rock, by inhibiting air flow through waste rock piles, and by decreasing the quantity of water flow through the waste pile due to evapotranspiration.

Revegetation usually involves the following processes:

1. Modification of waste pile shape to minimize erosion, and provide a stable platform for planting the vegetative cover,

2. Provision of a soil or upper surface granular medium with characteristics conductive to plant growth, including: sufficient water holding capacity, rainfall or irrigation, nutrients, and pH. This medium must be non-toxic to plants, as well as meeting toxicity and carcinogenicity standards for human ingestion,

3. Provision of amendments to facilitate plant growth. Typical amendments include mulch, fertilizer, and liming materials,

4. Planting of the vegetative cover. Plant selection is based upon compatibility with soil, ecological compatibility (generally requiring the use of indigenous species), and ability to form a self-sustaining cover that is resistant to erosion.

The chemical properties of waste rock can challenge efforts to create a lasting vegetative cover. In most cases, a layer of topsoil, including one or more soil amendments, is added. For example, when mixed with topsoil, organic mulch will retain moisture, uptake metals and enhance slope stability. Soil pH can be adjusted with lime or limestone. Nitrogen is usually deficient in mined lands. Planting leguminous species, such as clover will add nitrogen to waste materials, but this approach may not be consistent with normal requirements to use only native or indigenous species in reclamation. The use of fertilizer accelerates growth and establishment of a binding vegetative cover, as well as providing an immediate source of both nitrogen and phosphorous; however both nitrogen and phosphorous are environmental contaminants, and have impacts on algal growth in downstream lakes and streams. Before vegetating mine waste areas, soil analyses should be completed to identify the need for soil amendments. The cost of vegetating waste rock piles is greatly dependent on site condition, slope, and waste material type. The cost of providing soil amendment, seed, and fertilizer is estimated to be in the order of approximately $0.05 per square foot ($2000 per acre). The cost of site preparation, provision of topsoil, erosion protection, and other work to allow the vegetative cover to be successful is usually many times this amount. For the purposes of cost estimation, revegetation of waste rock piles in the steep slopes which typify the project area is assumed to require an amount of $0.50 per square foot ($20,000 per acre).

5.3.3 Cover Technologies

Covers are physical barriers designed to limit the influx of oxygen and surface waters to wastes beyond that protection provided by revegetation. This can be accomplished by submerging the pile under water (wet covers), by covering the pile with low hydraulic conductivity solids (dry covers), or by constructing covers which limit the transmission of water through the cover (capillary barriers, vegetative covers).

The choice of a dry cover material should be based upon the effectiveness as a barrier to air and water, resistance to erosion, local availability and cost. Covers often require modification of the surface profile and diversion of surface drainages, particularly in steep terrain such as exists at the project area. Covers constructed of locally derived materials having relatively low permeability are in common use in mine waste reclamation. Composite covers such as impermeable membranes and capillary barriers are less widely used for mine reclamation because of cost.

5.3.3.1 Submerged Disposal

Submergence of waste rock under water can eliminate ARD production by reducing oxygen availability. In the West Shasta Copper-Zinc District, significant areas of mill waste and mine waste material are already covered by Shasta Lake. The large volume of waste rock material, the elevation above sea level, and the steep terrain would physically prohibit this remedial alternative in the West Squaw Creek drainage.

5.3.3.2 Impermeable Barriers

Impermeable barriers include native materials such as clay or bentonite with permeability less than 1×10^{-6} (cm/sec) or synthetic covers made of HDPE or related materials. With the recent pressure to improve municipal solid waste landfills, significant improvements have been made to the quality and construction of synthetic liner and capping materials. Unfortunately, the placement of synthetic and clay barriers is difficult on slopes greater than 3:1, horizontal to vertical. This is due to the inability to operate equipment on steeper slopes and to anchor the barrier material. In the case of clay or bentonite barriers, the slopes must be gentle enough to allow the on-site compaction of the material to a set density, which would not be feasible in the waste rock in West Squaw Creek. Other barrier methods, such as shot grouting, may be used to encourage runoff rather than infiltration of water through the waste rock material; however, these alternatives are not considered impermeable barriers. Movement and regrading material would be required prior to construction of any type of barrier layer due to the impossibility of working conventional equipment on such slopes.

5.3.3.3 Capillary Barrier Covers

Capillary barrier covers are multi-layer or composite covers that apply capillary principles to maintain high-water saturation in the actual barrier layer. This is accomplished by installing a layer with high hydraulic conductivity (coarse sand) below a layer with low hydraulic conductivity (compacted clay). The high-hydraulic conductivity layer remains unsaturated, and capillary suction forces within the overlying low-hydraulic conductivity layer prevent drainage from the layer. However effective, capillary barrier covers cost significantly more than single layer covers and are faced with the same limitations on slope and compatibility. The estimated cost of constructing a cover that includes a capillary barrier is over $1 per square foot, not including the regrading costs. The cost is considerably greater in extreme cases and cannot be applied on sloping surfaces.

5.3.4 Stabilization

The ability of waste rock materials and eroded sulfide-bearing materials to produce ARD may be reduced by stabilization. Stabilization includes chemical or physical modification in which the materials are solidified such that they cannot erode or be chemically altered. Stabilization can be achieved by a variety of methods including grouting, mixing, and in situ isolation.

5.3.4.1 Admixture

The admixture process involves the addition of the stabilization material to the waste and placement of the resulting mixture into forms, or in some containment facility where it hardens. Admixture materials include Portland cement, fly ash, rubberized materials, or silicates. Such application on extreme slopes is not feasible.

5.3.4.2 Isolation

Isolation of wastes involves the construction of a containment facility, surrounding the wastes in an in situ system, which prevents the ingress or egress of water and oxygen to the waste materials, thus preventing movement of contaminants to the environment. The in situ isolation of waste piles using grouting technologies is not widely used.

5.3.4.3 Chemical Stabilization

An alternative to removal or isolation of waste rock is to chemically alter the waste rock. Chemical stabilization is typically carried out by physically mixing reagents with wet soils and allowing chemical reactions to take place. The chemical reactions may include neutralization, precipitation, and absorption. Neutralization entails using soil amendments to raise pH of acidic waste rock. Potential soil amendments include crushed limestone, dolomite, hydrated lime, calcareous soils, fly ash, and municipal incinerator ash. In general, long retention times are required to make treatment effective. At mines within the proposed project area, long retention times are not feasible due to the limited space and steepness of the surrounding terrain.

5.3.5 Bactericides

Thiobacillus ferrooxidans are a class of bacteria that oxidize sulfides and increase the rate of sulfide oxidation. Inhibiting or destroying the bacteria can slow the rate of acid production from pyritic materials in waste rock piles. Anionic surfactants are available that can destroy the bacteria and reduce the rate of pyrite oxidation. Bactericides work best when applied to fresh, unoxidized sulfides commonly found at active mine sites (Ziemkiewicz and Skousen, 1996). Surfactants alone, however, will not permanently control ARD, as eventually the surfactants degrade or leach out of waste material. Bactericides should be used in combination with other control measures, such as soil caps and vegetation. The surfactants currently in use are simple to use but expensive, and results have been generally disappointing in application to hard rock mining waste such as that on MRRC properties. Cost of bactericides is approximately $1,000 per ton of bactericide, with typical application of one ton per acre.

5.4 TREATMENT

5.4.1 Wetland Treatment System

Constructed wetlands are a somewhat new concept, and considering longevity, a relatively inexpensive and low-maintenance method of treating ARD. Wetlands improve the water quality of ARD by creating reducing conditions and adding alkalinity. Both processes result in removal of ARD metals from the water column by the following mechanisms:

- Precipitation of metal due to neutralization of ARD,
- Plant uptake of metals,
- Metal absorption to organic substrates,
- Oxidation and hydrolysis reactions,
- Co-precipitation of metals with iron,
- Sulfate reducing bacteria to precipitate metals.

Wetlands require relatively long retention times, a constant water supply, relatively stable flat ground, and a large space (at least 1-acre for each 70 gpm to be treated). In general, the West Shasta Copper-Zinc District is not conducive to wetland technologies. This is due to infrequent but heavy rainfall and steep terrain affording relatively small flat areas for construction. However, wetlands may provide some benefits to selected ARD flows in the project area.

There are several construction designs for wetlands based on influent water quality and the goals of wetland treatment, including:

5.4.1.1 Aerobic Wetland

Aerobic wetlands are plant growth areas onto which the water is introduced at the surface. Contact with air, plant communities, and underlying soil is relied upon to clean the water. These systems require large areas to be effective. Treatment rates in the order of 10 gpm per acre of wetland are normal, and aerobic wetland treatment cells require large area of flat terrain. Water that has net alkalinity is best suited for treatment by aerobic wetlands. Because the water at the MRRC mines is acidic, this treatment method would not be effective for removing metals from the acidic water. In addition, few areas sufficiently large enough to accommodate a wetlands treatment can be found in the steep terrain in the West Squaw Creek watershed.

5.4.1.2 Anaerobic Wetlands

The design of anaerobic wetlands varies greatly depending on the location, the nature of the liquids to be treated, and the requirements for discharge. A typical design consists of a base layer of limestone overlain by organic material. Water to be treated is introduced via the limestone base layer. Anaerobic wetlands require an area of at least 15 square meters for every liter per minute of flow. Construction must be on reasonably flat topography. As with other ARD treatment systems, the metal uptake capacity and treatment performance of constructed wetland usually decrease when influent flow rate or metal loads increase. The estimated cost of installing the Keystone wetlands unit was $100 per square foot.

5.4.2 Passive Treatment System

Surface water flow can be passively remediated using limestone treatment consisting of the placement of sized limestone material in a pond, reservoir, channel, or mine portal. Limestone treatment increases the pH of mine drainage and immobilizes heavy metals by precipitating metal hydroxides and oxides. Treatability studies suggest that a contact time of four hours or more is generally required for effective treatment of metals in ARD. Although limestone treatment is a cost-effective way to reduce metal loading, the remaining concentrations of metals in water after treatment may still be sufficiently high to impact aquatic organisms. Passive treatment systems require relatively long retention times, relatively stable, flat ground, and large, relatively flat spaces for construction. Past feasibility studies suggest limestone treatment at the site would be successful in reducing metals loading. It is unlikely that passive limestone treatment alone would effectively meet NPDES water quality objectives.

Alkalinity-producing systems (APS) are a common passive treatment system. APS systems contain a base layer of limestone overlain by organic material. An APS is designed to treat water with net acidity, reduce sulfate to sulfide, and immobilize heavy metals. The APS may be better suited for this site because there is no need for a steady supply of water. In addition, APS systems are more resistant to erosion and require less maintenance. The cost of installing an alkalinity producing system is estimated to be $15 per square foot. The area required for installation is similar to a constructed wetland. APS installation may not be feasible for most locations at this site, due to steep slopes and limited access.

5.4.3 Active Treatment System

An active treatment system pre-filters the ARD, followed by chemical treatment with lime to neutralize the pH. This results in precipitation of metal hydroxides and oxides, sludge removal and clarification using settling ponds. Sludge generated in treatment process must be disposed of in approved landfills. These treatment systems require a large working area, significant quantities of energy, such as electricity, continual operation monitoring, and maintenance. The capital cost for an active system to process 1,000 gpm of ARD of moderate metal and acid concentrations would be expected to cost on order of $10 million, and operating and maintenance would cost between $2 million and $4 million per year.

Active treatment systems are not feasible for the project area mine sites. This is due to the remote location (making it difficult and sometimes impossible to transport materials in and out), limited space, lack of sludge disposal areas, energy consumption requirements, and requirements for constant monitoring. In addition, the flows are highly variable, which could result in treatment bypass. In general, there is not sufficient area to create significant water storage capacity at the mine sites to allow routing of flows or to build a plant of sufficient size. In addition, because the mine sites are scattered over a large area and at various elevations, it is infeasible to collect the flows and direct them to a plant site. This system is further considered impractical because heavy snows make access impossible at times during winter months and maintenance of such a facility would be difficult, if not impossible.

5.5 SUMMARY

A summary of the BMPs evaluated for the West Squaw Creek mines is provided in Table 5-4. The estimated costs included on this table reflect construction costs if the alternative was implemented, or reflects the estimates included in the original feasibility study.

Table 5-4
FEASIBILITY OF REMEDIAL ALTERNATIVES

Method	Materials	Cost ($)	Units	Use in WSC	Comments
Underground Workings					
Bulkhead Seal	Bulkheads	$300,000	Bulkhead	High	All portals with year round flow have been sealed.
Backfilling	Rock, soil to plug mines	$15	Ton	Low	Backfilling was not considered because portal plugging and passive treatment has been successful.
Injecting Neutralizing Materials	Grout, flyash, limestone	$250	Ton	Low	In attempt to improve quality of seepage from Keystone bulkhead seal, limestone injection was tried. Results were poor and a wetlands cell was constructed to treat the residual discharge.
Injecting Organic Materials	Organic matter	$150	Ton	Low	MRRC is conducting an organic injection pilot study in a nearby watershed. The results are mixed. This alternative has not been implemented in West Squaw Creek.
Surface Water					
Diversion Channels	Concrete, HDPE, gabions	$100	Lin. Ft.	High	Channels diverting water around waste rock piles have been applied successfully, especially in the Windy Creek drainage.
Waste Rock					
Underwater Disposal	Lake or wetland cover	Varies		Low	Not feasible in mountainous topography.
Consolidation and Grading	Soil, rock, vegetation	$5 - $10	Ton	High	Waste rock piles in the vicinity of the Keystone Mine and associated with the Upper and Lower Windy Camp portals have been consolidated and capped with native material.
Revegetation	Soil, vegetation	$0.50	Sq. ft.	High	Waste rock piles in the vicinity of the Keystone Mine and associated with the Upper and Lower Windy Camp portals have been revegetated.

Table 5-4 (continued)
FEASIBILITY OF REMEDIAL ALTERNATIVES

Method	Materials	Cost ($)	Units	Use in WSC[1]	Comments
Capillary Barrier	Rock, soil, vegetation	$1	Sq. ft.	Low	Not applied because of high annual precipitation (>60 inches) and steep topography.
Synthetic Cover	Liner, soil, vegetation	$0.50	Sq. ft.	Low	MRRC constructed a lined containment cell in a nearby watershed. This alternative has not been applied in the West Squaw Creek watershed.
Stabilization					
Physical	Cement, chemicals, isolate	$250	Ton	Low	Not applied in West Squaw Creek
Chemical	Chemical amendments	$300	Ton	Low	Inability to meet retention time requirements in steep terrain.
Biological	Bactericides	$0.25	Sq. ft.	Low	Not a permanent solution to ARD. Public opposition to use.
Treatment					
Aerobic Wetland	Soil, rock, plants	$1	Sq. ft.	Low	Not applied in West Squaw Creek
Anaerobic Wetland	Soil, rock, plants	$100	Sq. ft.	High	Limited by steep terrain and access. One WLTC has been constructed where topography allows.
Anoxic drain	Sealed limestone drain	$10	Sq. ft.	Low	This alternative was applied unsuccessfully to address residual discharge from the Upper Windy Camp portal.
Active Treatment	Limestone, flocculants	$2	1,000 gal	Low	Not considered in the West Squaw Creek watershed because there is no power, water, or reliable access to most areas.

Note:
[1] "High" in the Use category indicates that the alternative was implemented and was successful at reducing ARD. "Low" indicates the alternative was not implemented or it was implemented and did not significantly reduce ARD.

SECTION 6
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6.0 REFERENCES

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